523
L81w

REMOTE STORAGE

NCHESTER SCIENCE LECTURES FOR THE PEOPLE.

EIGHTH SERIES. WINTER SESSION, 1876.

WHY THE EARTH'S CHEMISTRY IS AS IT IS.

BY J. NORMAN LOCKYER, ESQ., F.R.S.

LECTURE I.

In the three preceding lectures of this series, the chemical constitution of the Earth has been brought before you, and my part in the course, as I understand it, is to deal with the bodies, so far as we know them, which people space; in order that the earth's true place in nature, so far as its chemical and physical constitution is concerned, may be ascertained, and the reasons for that constitution inquired into.

For this purpose it is necessary that I should enter at some length into the constitution of those masses of matter which lie beyond the earth on which we dwell, and even beyond the system, and, it may be, the universe, of which we form a part. And you will naturally—some of you at least—ask, How is it possible that such knowledge as this has been attained? Prof. Roscoe, when he wished to tell you about the chemical composition of the earth's crust, was enabled to bring before you specimens of its different constituents, and could tell you how these specimens had been handled and weighed and experimented upon in different ways in his laboratory; but when we have to deal with the chemical constitution of bodies so

p 53637

many millions of miles removed from us that we know a matter of fact that the light which now enables us to see th must have left them hundreds of years ago, it is perfec clear that such methods as those indicated by Dr. Roscoe entirely powerless. In fact some other process is n with one exception. There are certain celestial mes come to us from time to time which we can touch an we can handle—I mean Meteorites, which appear falling stars or aërolites; bright, beautiful objects, li rockets which are going up to-night, and which, fort very for science, last long enough to come down to the solid crust of the earth, where they cool and where we may subsequently examine them, as Dr. Roscoe has already told you. But with this exception, it is clear to you that ordinary chemical processes are entirely out of the question.

The progress of physical science has been in this wise :— As man has grown older the earth on which we dwell has dwindled down. It began as the centre of the universe ; it has ended as a small mass of matter revolving round what probably is a small star—I mean the sun. But although the progress of science has been thus in a way to degrade the earth, I am sure you will think with me that man's intellect has been a distinct gainer by the process ; for it is not too much to say that as the earth's place in nature has dwindled down, so has man's mental horizon been extended. That is very well shown by two fundamental considerations which I must bring before you in the first instance. In the year 1610, or thereabouts, that is to say, about two centuries and a half ago, thanks to the labours of men in Holland and in Italy, but chiefly to the genius of the immortal Galileo, the telescope was invented, and we got an untold addition to our mental wealth. The skies were peopled by means of the telescope, and the earth, which up to that time had been supposed the centre of everything, was put in its right place; bodies were observed shining millions and millions of miles away—bodies which up to that time had bathed the earth with light without any response from the human eye ; and what was the result? Philosophers were enabled to class all the shining orbs of heaven into two great divisions—those bodies, namely, which shone like the sun with a light of their own, and those which shone by borrowed light. The bodies which were found to shine by borrowed light and not by any light of their own, were bodies which eventually were classed together

and termed the solar system—a family of planets which go round the sun, each in its proper path, each in its proper time; which are lighted up by the sun; which are warmed by the sun, and to the inhabitants of which the sun is the fountain of every kind of energy. We have from this classification the first great grouping of celestial bodies into those which shine by their own light, which, with the exception of the sun, are outside the solar system; and into those which shine by reflected light, which classification included all the bodies of the solar system except the sun. Now I will throw on the screen a diagram of the solar system, in order that you may exactly see which these bodies are, that reflect light, and in this case the light of the sun. I am very anxious indeed that you should understand the importance of this first classification, because the next one which I shall have to bring before you will go very much further into detail. We have, as representing the bodies of the solar system, first of all in the centre the Sun, which shines by its own light; and next, in the order of distance from it, Mercury, Venus, the Earth, Mars, a group of small planets called the Asteroids; then after them, Jupiter, Saturn, Uranus, and Neptune; Neptune being the last member of the solar family, so far as our knowledge at present goes.

When I call your attention to the next classification, I shall no longer have to refer to the illustrious Florentine, but to your own townsman, Professor Balfour Stewart, and to Professor Stokes. Their labours have given us another and more searching grouping, so to speak, by which we can go into much greater detail. This grouping is no longer based on the teachings of the telescope, but on the teachings of the spectroscope; and here, if you will allow me, I will state as briefly as may be the nature of this teaching, as you will find it of extreme importance, as we go along, to understand the terminology which I shall have to use. The important results to which we have arrived—thanks to the work of Stewart, Stokes, and others, and to the introduction of the spectroscope—can be shortly stated.

So long as Dr. Roscoe was telling you about taking a specimen of iron and analysing it, and taking a specimen of calcium and weighing it, and so on, it might not have been perfectly obvious to all of you that before you could recognise the existence of that calcium, and before you could see the beam of the scale go up or down, according to the precise weight of

it, a certain connection had been established between that calcium, let us say, and yourself—your consciousness. But when I shall have to tell of the chemical constitution of bodies thousands of millions of miles away, the necessity for some connection between our eyes—our consciousness—and those distant objects, will force itself upon us ; and it is important therefore at the threshold that we should refer to it. These distant bodies are visible to us by means of their unrest ; if all the bodies in space were absolutely tranquil we should never see them ; but the normal condition of everything in nature is a state of most beautiful and exquisite unrest. Scientific men call this a state of vibration ; but we need not quarrel about terms. Everything in nature, far or near, is in this state of unrest, and if it were not so there would be for us no external world. From every material substance, including these distant worlds, the vibrations of their smallest particles or of their largest masses come to us along a medium which scientific men call ether, not that they know all about it, but because it is necessary, in order that their work may go on at all, that they should assume that there is a something infinitely finer than matter, and not at all like the attenuated matter which pervades all space. This ether forms the highway along which the vibrations due to the state of unrest of matter travel to our eye, and afterwards to our brain, thus begetting in our consciousness the impression of the material world.

Here, then, we have a vibration of the most distant mass of matter in the universe communicated to our optic nerves by means of this ether. How comes it that any chemical knowledge can be acquired concerning these bodies? In this way. The spectroscope tells us that when we break a mass of matter down to its finest particles, or, as some people prefer to call them, ultimate molecules, the vibrations of these ultimate parts of each different kind of matter are absolutely distinct ; so that if I get the ultimate particle, say of calcium, and observe its vibrations by scientific means—what those scientific means are I shall show you by and by—we find that the kind of unrest of one substance—of the calcium, for instance—is different from the kind of unrest or mode of vibration—which is the same thing—of another substance, let us say sodium. Mark well that I say when we have brought these substances down to their ultimate or to almost their ultimate finenesses, because until we have done so the

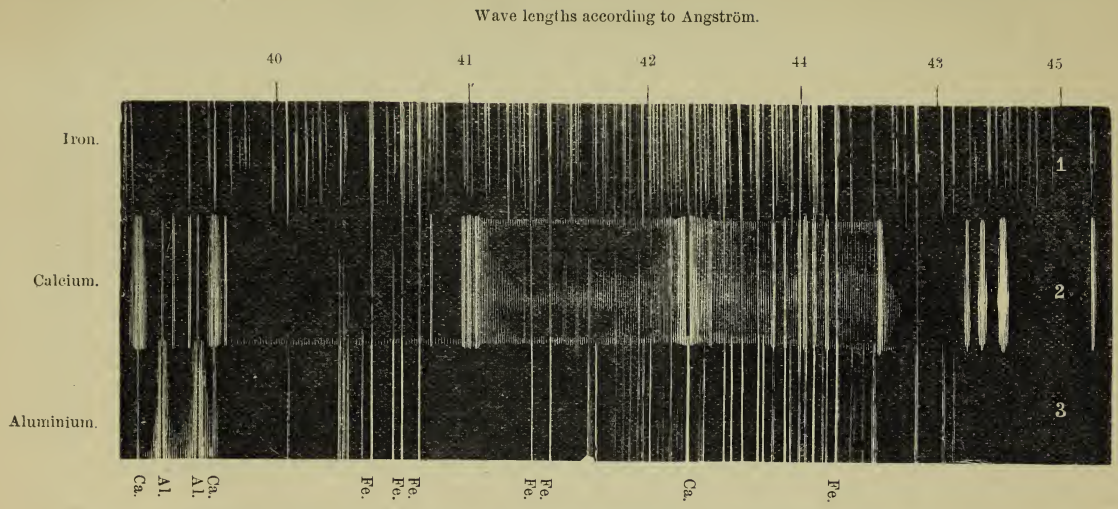

FIG. 1.—Comparison of the line spectra of Iron, Calcium, and Aluminium, with common impurities. Copy of a photograph by Lockyer, in which, by dividing the slit of the spectroscope into sections, and admitting light from the various light sources through them in succession, spectra of different elements are recorded on the same photographic plate.

vibrations of the larger molecular aggregations are absolutely powerless to tell us anything about their chemical nature, but they are full of teaching as to physical conditions.

Now we know that when we bring down a substance to its finest state and observe, by means of the prism, the vibrations it communicates to the ether, we find that using a slit in the spectroscope and making these vibrations paint different images of the slit, we get at once just as distinct a series of images of the slit for each substance as we would get a distinct sequence of notes if we were playing different tunes on a piano. I have here a photograph which has been produced by such vibrations. I hope first to show you on the screen what is called the line spectrum due to the smallest particles of calcium and aluminium; and if I am successful you will perfectly understand the meaning of the term line spectrum. Here are the lines by which the metal calcium is recognised when the vibrations of its finest particles are observed by means of the spectroscope. The two central lines give you also the vibrations due to aluminium. If you look to the other part of the screen you will think perhaps that you are dealing with a different order of phenomena altogether, and in that you will be perfectly justified. In truth we have here on the same screen not only the line spectra of calcium and of aluminium, but what is termed the channelled-space spectrum of carbon; that is to say, while the calcium and the aluminium have been driven down to their finest states of separation by dissociation, the carbon has not been driven down so low, and therefore we get a different kind of spectrum.

These vibrations having been rendered, I hope, intelligible by means of these drawings, this important consideration comes into play—that whenever any element finds itself in this state of fineness and therefore competent to give rise to these phenomena, it will give rise to them in different degrees according to certain conditions. The intensest form in which they may be brought before you is observed when we employ electricity. In a great many cases the vibrations may be rendered very intense by heat. The heat of a furnace or of gas will, for instance, in a great many cases, suffice to give us these phenomena; but to see them in all their magnificence, their most extreme cases, we want the highest possible temperatures, or better still, the most extreme electric energy. What we get is the vibration of these particles rendered visible

to our eye by the bright images of the slit or by their bright "lines."

But that is not the only means we have of studying these states of unrest. We can study them almost equally well if, instead of dealing with the radiation of light from the particles themselves, we interpose them between us and a light-source of more complicated molecular structure, and hotter or more violently excited than the particles themselves. From such a source the light would come to us absolutely complete, as it is coming to us now from that gas; that is to say, a perfectly complete gamut of waves of light, from extreme red to extreme violet. I say that when we deal with these particles between us and a light-source competent to give us a *continuous spectrum*, then we find that the functions of these molecules are still the same, but that their effect upon our retinas is different. They are not vibrating strongly enough to give us effectively light of their own, but they are eager to vibrate, and, being so, they are employed, so to speak, in absorbing the light which otherwise would come to our eyes. So that whether we observe the bright spectrum of calcium or any other metal, or the absorption spectrum, we get lines exactly in the same part of the chromatic gamut, with the difference that when we are dealing with radiation we get bright lines, and when dealing with absorption we get dark ones.

Now that being so, it will be perfectly clear to all of you that we have it in our power to enormously extend the inquiries started by Galileo. We need no longer be content with dividing the non-terrestrial bodies into those which shine by their own light and those which shine by reflected light, but we may make a classification of this kind. We have first of all those bodies which we can study by means of the radiation of their molecules, that is to say bodies in which the mere state of unrest, as I have ventured to call it, the mere giving out of light by the molecules of which these celestial masses consist, is the only thing in question. Then again, we have another class in which we deal not only with the radiation of the interior, but with the absorption of the molecules or particles by which each body is surrounded. Then we have, to come back to Galileo's classification somewhat, those bodies which we observe by means of light which they reflect to us. Then again there may be, and in fact there is, a class of bodies which, although they send their light to us by reflection, still make this light, so to speak, pay

a second toll on its passage, and it comes to us reflected and absorbed.

Nebulæ and Comets.

When we examine into the various bodies which people the skies, we find that among those which can be studied by means of their radiation alone there are two of the very largest groups. I refer to nebulæ and comets. Let us first deal with the nebulæ. A very small telescope indeed is all that is requisite to see some of the most magnificent nebulæ in the heavens. I will throw on the screen Lord Rosse's drawing of the nebula of Orion; but before I do so I should like to show you how the spectroscopic addition to our knowledge has been secured. For this purpose I can show you a drawing of the eye end of the largest telescope in England at the present time, one belonging to a North-countryman, Mr. Newall, of Gateshead, and you will at once understand how the spectroscope has been used to aid the telescope to obtain these additions to our knowledge which I shall have to bring before you. Here is the eye-piece end of Mr. Newall's telescope, which, magnified in this way, is perhaps about life-size, the object-glass being some twenty-five inches in diameter, and the focal length thirty or thirty-one feet. At the eye-piece end of the telescope we have attached to it at the focus the spectroscope, with a number of prisms depending upon the amount of light which each heavenly body which has to be investigated gives out. In this drawing I have shown the greatest number of prisms which are used when it is a question of observing the sun; but, as you will readily understand, if instead of observing the light of the sun concentrated by this enormous instrument, it is a question of observing the nebulæ and some of the fainter stars, then, as there is always a loss of light by making it traverse through any great thickness of glass, the number of prisms is much reduced; so that you may say broadly that we have the greatest possible number of prisms for observing the sun, and the smallest possible number of prisms, say one or two, for observing the spectra of the nebulæ and the spectra of the fixed stars —at all events of the fainter ones. I propose, in dealing both with the nebulæ and with comets, first to refer to the telescopic appearance of these heavenly bodies, and then

afterwards draw attention to the spectroscopic results which have followed.

The question of the chemical and physical constitution of the nebulæ is one perhaps of the most interesting in the whole range of astronomical science, and it has occupied the attention of our most illustrious astronomers. Having now before you the *modus operandi*, I will throw the drawing of the nebula, which

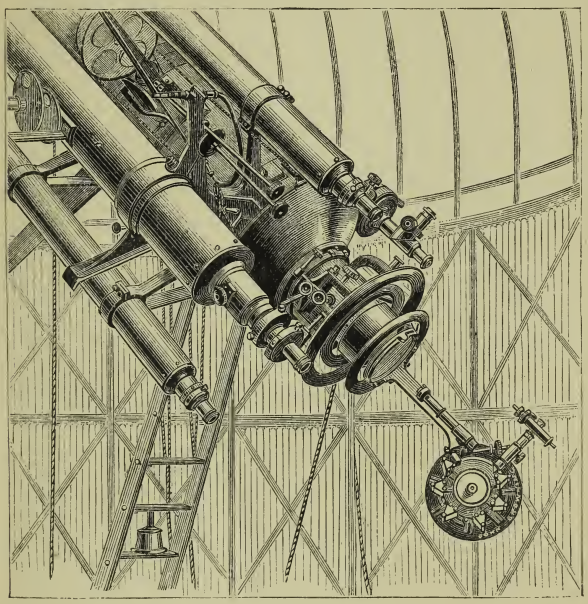

FIG. 2.—The eye-piece end of the Newall refractor (of 25 inches aperture) with spectroscope attached.

in these latitudes is most easily seen with the smallest instrument, and which, although it can be thus seen, is nevertheless one of the most magnificent objects in the whole heavens: I refer to the nebula of Orion. The first thing that strikes us about this nebula is its intense irregularity; there seems to be nothing celestial about it. Here and there we have great waves of light going along in diffuse courses from the central portion. Here

and there we have stars surrounded by a smaller nebulosity. Here again we have stars without any nebulosity at all ; and look where we will, we see fleecy contortions and the most wondrous irregularity. Now it was not to be wondered at

Fig. 3.—Copy of Lord Rosse's drawing of the Nebula of Orion.

that with the earliest telescopes the wildest guesses and the most profound thoughts were associated with these strange bodies. If we look at the works of Tycho Brahe and others, before the time of the astronomers of the last century, we find

them all occupied with an attempt at understanding the physics and the chemistry of these strange cosmical masses. Some were content to look upon them as fire-dust; others saw in them enormous star clusters so infinitely removed that each element of the nebulosity might represent a single star, the single star being so far away, however, that, like the Milky Way, which we know to be composed of stars, to the naked eye the individuality of the stars did not come out. In the last century however, when Sir William Herschel with his wonderful perseverance at last had succeeded in eclipsing all former optical instruments by his magnificent forty-feet instru-

Fig. 4.—Nebula in process of condensation.

ment at Slough, then indeed the scientific study of nebulæ may be said to have commenced, and in a few years he had made lists of thousands of nebulæ; and his son, Sir John Herschel, later went to the Cape and added thousands more. Nearer our own time the magnificent instrument of Lord Rosse, at Parsonstown, has added to our knowledge, so that now the list of nebulæ is very considerable indeed. You will ask, Has the wonder connected with these strange objects been reduced by extended observations? I think I shall be able easily to show you that it has not been so reduced. Here, so far as form goes, we get a complete absence of all form—

absolute irregularity. Allow me to call your attention to some other drawings of nebulæ made by Lord Rosse, in which the irregularity typified by the nebula of Orion has given place to something absolutely different. Here we have an approximation to form and regularity, although the regularity is of different kinds. We have spiral nebulæ, annular nebulæ, and, as I may term them, *Saturnine* nebulæ. Note well the fact that the moment we leave the extreme irregularity of the nebula of Orion we always have to do with a condensation of some kind or other; in some cases with something between concentric and spiral convolutions round the central condensation.

Here is another series of nebulæ observed in the first instance by Sir John Herschel, which will intensify the classification to which I have referred. We have again spirals

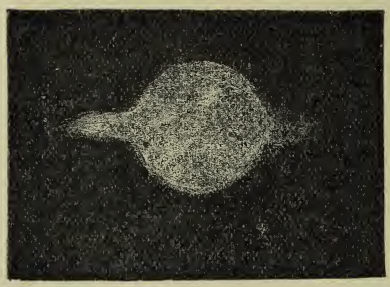

Fig. 5.—Saturnine Nebula.

and double spirals. Finally, I will show you one of the most magnificent spiral nebulæ in the heavens from the same set of drawings. You see that the central condensation is fed, as it were, by spirals in all directions, some of them having condensations on the different branches. Now, Humboldt was not in possession of all these observations which I have been able to bring before you to-night, but he sums up in the first volume of his *Cosmos* these various forms of nebulæ in a very effective way. This summary will well repay perusal.

Now what are the modern ideas of the constitution of these strange bodies? I have already referred to the ideas of Tycho Brahe, Cassini, and the earlier observers. The work of the two Herschels left it as highly probable that these nebulæ

were really masses of cosmic dust, so to speak, or some kind of gaseous or vaporous material, which took these strange forms because there was nothing solid about them. But when Lord Rosse, with improved optical means, investigated some of the nebulæ which had been called irresolvable—a name given because no telescope up to that time was able to break them up into separate stars—he found that his telescope did break them up into distinct points of light, and then for a time in the pre-spectroscopic age, as one may call it, opinion swung round, and held that these nebulæ simply appeared as nebulæ not because they did not consist of stars, but because they were so far away that we could not see the separate stars of which they were composed. But not many years ago Dr. Huggins—to whom belongs the credit of having first turned the spectroscope

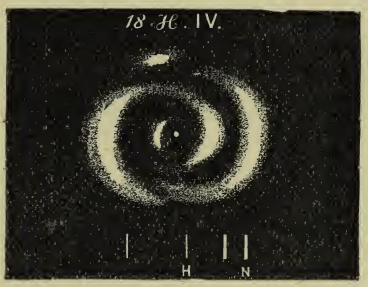

FIG. 6.—Nebula with rings.

on to the nebulæ—was enabled to show beyond all shadow of a doubt, that we had in the nebulæ something absolutely and completely distinct from stars. Dr. Huggins found, on turning his spectroscope upon several of these bodies, that the spectrum which he got from all of them was most characteristic. It was a bright line spectrum, and there was one line which was common to all of them. In the lower part of the diagram the bright lines visible in the spectra of the different nebulæ are shown; and below, for purposes of reference, Dr. Huggins has shown the positions of various bright lines in the spectra given by other substances. There, for instance, in the blue-green, is the bright line due to hydrogen; there is another line in the green due to magnesium; a line in the yellow due to sodium; and so on; and with these points of reference we

can easily determine the place in the spectrum of the three bright lines which Dr. Huggins found to be visible in the spectra of almost all the nebulæ examined; the differences between nebulæ and nebulæ, as I understand them, being indicated by the relative intensity of the lines, and the amount of continuous spectrum associated with them.

Having this enormous addition to our knowledge—the fact, namely, that the light given out by nebulæ is perfectly distinct from the light given out by stars—men of science were able to study the nature of nebulæ from a perfectly new standpoint.

One of the lines of the nebulæ is really coincident with a line of hydrogen, or, in other words, we have to deal with hydrogen gas when we are dealing with nebulæ. This has

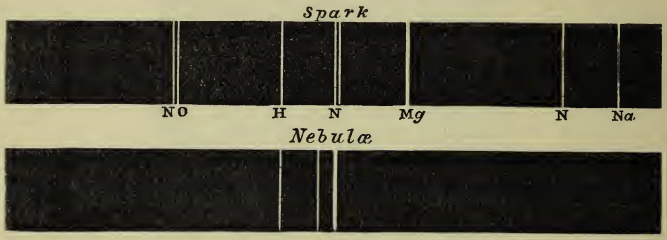

Fig. 7.—Spectrum of the Nebulæ (Huggins) compared with the bright lines of certain elements.

been a most interesting and important point of departure. Dr. Huggins is of opinion that the nebulæ consist of masses of hydrogen gas; that there is nothing solid in the nebulæ, that it is a mere question of incandescent hydrogen, associated with something else, the chemical constitution of which has not yet been thoroughly established, because Dr. Huggins, with all his diligence, has not been able from his examination of the other chemical elements known, to get lines corresponding to those other two which we saw on the screen. But that is not the only view held as to the constitution of nebulæ. Sir William Thomson and Professor Tait consider it extremely probable that the nebulæ, instead of being masses of gas, may consist of clouds of stones. Now this at first seems so entirely at variance with the spectroscopic result, that it is

not to be wondered at that the idea was at first considered to be somewhat *bizarre* and strange ; but if one comes to think the matter out, one finds that there is a great deal of method in this strangeness, because Sir William Thomson and Professor Tait point out that if you had a cloud of stones, each one of which was in motion, and therefore liable to come into collision with some other stone now and then, you would get heat quite sufficient to render any circumambient gas incandescent ; so that the phenomena of the spectroscope could be explained equally well on the assumption of a cloud of stones, providing always that you could at the same time show reasonable cause why these clouds of stones were "banging about" in an atmosphere of hydrogen. But nebulæ are not the only things in the universe which these distinguished Scotch professors imagine to be composed of clouds of stones. I think it is better therefore that I should postpone the further discussion of this point until we have become acquainted with the second class of bodies, which we study by means of their radiation—I refer to comets.

Comets.

Now when we pass from a nebula to a comet, it is clear that we come to a body of a perfectly different order in the celestial economy. Comets are distinguished from the nebulæ in many ways. The nebulæ, as a rule, are very far removed from us, so far that we have not the least idea of the distance of any one of them—we know that they are not within certain limits, and that they are also at rest apparently among the stars, while the comets are erratic bodies, which are now in our system, and now out of it ; now close to us, and now infinitely removed in the depths of space.

Further, we know that the comets are not at all like the planets any more than they are like the nebulæ, because while our planets as a rule, excepting the smaller members or minor planets of the system, keep to one plane round the sun, called the plane of the ecliptic, which we may liken to a racecourse, round which all these planets pursue their revolutions—the comets do not keep to this plane, for they are as likely to dash into our system from above or below as they are to come into our system on the same plane as the planets. But more than this, while all the planets of our system are bound together by a motion which is always in the same direction

round the sun, when a comet comes into our system it is just as likely to go round the sun in an opposite direction. So that in the comets we have a complete differentiation between comet and nebula on the one hand, and comet and planet on the other.

I have here two or three general views which will give you a rough idea of the telescopic appearances of these strange visitors to our system. The peculiarity connected with comets generally is a double one—they have a bright head, and they have one or two or several appendages, called tails, which go from the head in a certain direction. There we have a comet with two tails—here with three; but these are not different comets; that is the comet which appeared in 1858, as seen at two different times. These views will give you a general idea of the appearance of comets, and of the way in which they travel among the stars. The physical interest of comets, which I shall have to call your attention to, is more intimately connected with the heads than with the tails; and I shall therefore hope to show you two or three more drawings, in which the heads of these comets will be in question. The characteristics of the heads are chiefly these—that in some cases we have to deal with what are called jets. The brightest point is called the nucleus of the comet, and the jets are so called because they seem to shoot out from the nucleus very much as the sparks shoot out of a squib.

Drawings of a comet, as seen at different times, show how these jets vary in appearance and direction. Instead of jets, some comets present phenomena of a very different character, called envelopes, which are thrown off concentrically from the nucleus. These envelopes are indicated in this drawing of a comet, made by Father Secchi in Rome. These then are the two physical peculiarities about the heads of comets; and you will see at once that we have something perfectly distinct from the nebulæ and the planets, and that one class of comets is at first sight different from another. The envelopes have been observed to rise from the nucleus with perfect and exquisite regularity in exactly the same way that the jets swing backwards and forwards. So much then for a very rough telescopic idea of the phenomena of comets.

What then says the spectroscope? I will now show you the diagram which I showed you before, in order to call your attention to another part of it. Formerly I called your attention to the spectrum of the nebulæ. I will now call your attention

to the spectrum of comets, and I am glad to have both the diagrams on the screen at the same time, because you will see that the spectroscopic difference is just as great as the telescopic difference. Now let me ask you to recall one of the first photographs I showed you—that of the carbon spectrum —and my definition of the channelled-space spectrum. You will at once recognise, I am sure, that here we have exactly that same kind of channelled-space spectrum that we had before. Side by side with this channelled space spectrum,

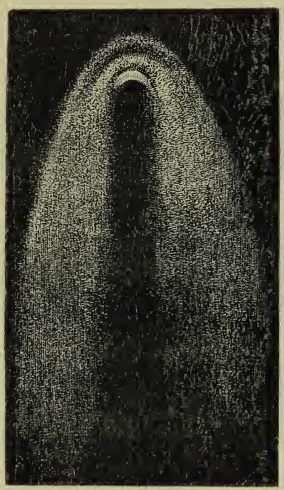

Fig. 8.—Concentric envelopes of Donati's Comet.

which is the spectrum of carbon, we have the spectrum of the comet, and you will see that the family likeness is very considerable, although it is true that the brightest portions of the spectrum of the comet are not absolutely coincident with the brightest portions of the spectrum of carbon which Mr. Huggins has drawn in the upper part of the diagram. What, then, is the meaning of this spectroscopic result? It is stated that if the spectroscope tells us anything, it tells us that we have to deal with carbon, or with hydro-carbon, as certainly in the case of comets, as we had to deal with hydrogen in the case of nebulæ. Here then we have a definite result with regard

to the brighter portions of the comets, that is to say, the nucleus, the envelopes, and the jets; but how about the tail? The same instrument, and the polariscope, when brought to bear on these longer appendages of comets, tell us that there we have perhaps no longer to deal with hydro-carbon, certainly not with hydrocarbon in a state of considerable unrest, for we do not get the characteristic spectrum of hydro-carbon; we get apparently from the tails merely sun-light reflected. Are we then to say that comets are built up of hydro-carbon? No. Here again Professors Thomson and Tait come in and insist strangely enough that comets as well as nebulæ are masses of stones; that, in short, a comet is a bit of a nebula,

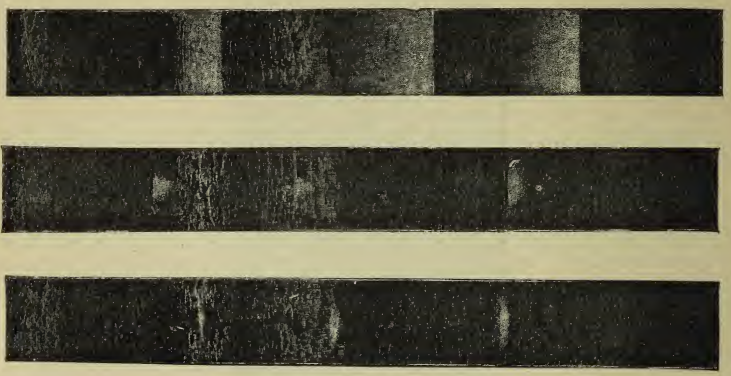

FIG. 9. – Cometary spectrum (Huggins).

differing from a nebula in this, that it is in violent motion as a whole, while the nebula is apparently at rest as a whole. You will find in *Good Words* of a few months ago an important article by Professor Tait, in which he goes into this question at very great length. He shows that if we have in the head of a comet a mass of stones, like a swarm of bees, banging about, and, at the same time, moving in an orbit around the sun, or it may be in its long path from the centre of our system to the centre of another system, and the stones colliding, you will get heat, and some gas will be evolved; some members of the mass will be quickened, while other constituents of the mass will be retarded in their motion, and

that in this way you have a probably sufficient explanation of the various forms which the telescope has revealed to us. And then finally he goes on to show that the result of these collisions would be such a smashing up of the constituents of the swarm that much finely-attenuated material would be left behind, sufficient to reflect sunlight, and to give rise to the phenomena of the tail.

Now, curiously enough, while these ideas have been evolving themselves, a distinguished Italian astronomer, Schiaparelli, had also arrived at the conclusion that comets were closely connected with swarms of meteors; and he arrived at this conclusion by an examination of the paths of the meteors and the paths of certain comets. Astronomers now know exactly when to look out for what they call a meteor-swarm, or a mass of shooting-stars. They know, for instance, that on the night of the 20th of April they will most probably see shooting-stars coming from the constellation Lyra, and these shooting-stars they call the Lyriad shower. They know also that on the 10th and 11th of August they will see other shooting-stars, this time coming from the constellation Perseus. These also they call the Perseids. On Nov. 13 and 14 the Leonids may be expected, that is to say, that then is the time to look out for shooting stars which come from the constellation Leo. Now if astronomers can tell you that on a certain night—that is to say, when the earth is in a certain position in its orbit—shooting-stars will appear to come from a certain part of the heavens, namely, some particular constellation, it is because they have become acquainted with the path of those meteors round the sun. They have, in fact been able to get a very concrete idea of the orbits of those meteors, in the same way that we have a concrete idea of the orbit of the earth round the sun. They can tell exactly where and when they cut the plane of the ecliptic, and other things which I need not bring before you in detail. After comets have appeared two or three times, astronomers can also form an equally definite idea of their orbit round the sun. Now, what Schiaparelli did was this—he compared the orbits of these meteoric swarms with those of some of the comets, and he found some of them identical. For instance, in the case of the shower of April 20th in each year he found that there was a comet observed carefully in 1861 with absolutely the same path; for those shooting-stars which radiate from the constellation Perseus on 10th August he found that a comet observed in 1862 had exactly

the same path; for the Leonids, which appear on 13th and 14th November, he found that a comet, observed and calculated out accurately in the year 1866, had exactly the same path. And

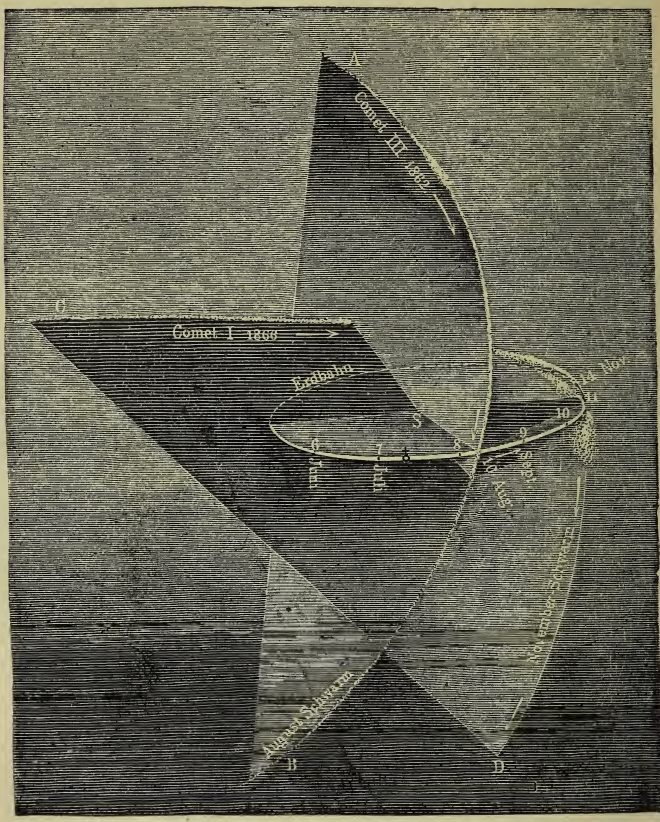

Fig. 10.—Diagram showing the paths of Comet I., 1868, and III., 1862, and their accompanying meteor swarms, and the points at which they cut the earth's path.

then with regard to the other principal group observed on the 27th and 28th November, he found that the falling stars seen in the constellation Andromeda on those nights had

exactly the orbit as a very well-calculated and most remarkable comet named after Biela the astronomer. Now, of course this suggestion of Schiaparelli gave an enormously increased interest to the investigation both of comets and meteors, and when the question was thoroughly gone into it was impossible to avoid the conclusion that when we have a shower of falling-stars we practically are going through part of a comet; and that when we see a comet in the sky we actually are seeing the behaviour of a swarm of meteors at a distance.

I hope to commence my next lecture by referring to some other considerations with regard to these meteorites, and then to call your attention to some experiments which suggest that the connection between meteors or falling-stars, comets and nebulæ, is of the very closest description.

LECTURE II.

In the latter part of the last Lecture I referred to the chemical constitution of comets, so far as the spectroscope enables us to determine this constitution; and I endeavoured to point out to you what the telescope had revealed to us with reference to their physical constitution. I also again dwelt on one of the great triumphs of modern astronomy—namely, the discovery by Schiaparelli of the intimate connection between falling stars and comets.

Meteorites.

Now, from the falling star to the meteorite is a step so small that nothing need be said about it by me to-night. The difference between a falling star and a meteorite is simply this—that a falling star is a small mass of matter which is entirely burnt up in its passage through the higher regions of our air, whereas the meteorite is a falling star big enough to give us some residuum after the energetic action of heat has worked its will upon it in passing through the atmosphere. Observations of the rapidity with which falling stars and meteorites traverse our atmosphere have shown beyond a doubt that a meteorite could travel, say from Manchester to London, in as many seconds as an express train takes hours. You may imagine, therefore, that owing to this very rapid motion through a medium—and a medium constantly increasing in density—such as our air, that a considerable resistance is offered to the passage of the meteorite. This arrested motion in process of time becomes developed into what we call heat, and as a result in all cases we get

luminous effects, with this difference, that, whereas in the case of the falling star, the luminous effect is the only thing we get, in other cases we get in addition to it the actual descent of what we may term a celestial messenger from the depths of space. Of course, having these meteorites—these larger masses—falling to the earth, so that we can handle them, a great deal has been learned about their chemical and physical constitution, as Dr. Roscoe has already told you. I need not dwell at any great length upon this, after what Dr. Roscoe has said; but I may state that, generically, these celestial messengers may be divided into four groups. We have those which are almost entirely metallic. We have those which are almost entirely stony. We have those in which the metallic and the stony constituents are mixed in various proportions; and in a fourth, or last class, in addition to the materials to which I have already referred, there are to be found various combinations of hydrogen with carbon, termed hydro-carbons.

We have, therefore, in the language of the meteoric chemist, siderites, those which contain iron; aërolites, those which are chiefly stony; siderolites, which are mixed, half stony, half iron and nickel; and then again the carbonaceous group. Coming from this generic chemical grouping, a word may be said as to their appearance. And here, if you will read (for I cannot go into this question in any great detail) the writings of Maskelyne and Sorby, you will become acquainted with some most extraordinary facts and coincidences. Some of the meteorites are stated to exactly resemble volcanic bombs; others resemble volcanic tufa; others again bear evidence of having being subjected to actions which we know nothing whatever about in this earth of ours. Mr. Sorby, for instance, has gone so far, and I have no doubt perfectly justifiably, as to state that in some meteorites which he has examined microscopically there is evidence to show that they were formed in a region where, so to speak, there was no gravity; that is to say, far away from the surface of any such body as the sun or our earth. When we come to the actual chemical elements which these meteorites contain, we find ourselves in a region where knowledge is extremely rich, compared to what it is at present in the case of nebulæ and comets. It is anticipating matters somewhat, but it is worth while to state that the complete list of the metallic elements of meteorites is almost identical with the complete list of metals in this list

(Table of Elements contained in the Sun, page 31). It is more than a coincidence, I think, that the chief metallic constituents of meteorites are almost identical with the chief metallic constituents of the sun. But strange to say, this is by no means the case when we come to leave on one side the metallic elements and come to the metalloidal ones, such as carbon, and sulphur. Up to the present moment there is no published observation of the existence of any metalloid whatever in the sun's atmosphere. That does not say they do not exist; but at present we know nothing definite as to their existence.

Given these meteorites, and assuming them to be the meteoric swarm which Schiaparelli postulates for the comets —that is to say, supposing that we see first in the heavens a body which we call a comet, observe it with the spectroscope, and get from it the spectrum of hydro-carbon; and then suppose that subsequently this very same body, consisting, according to hypothesis, of a swarm of meteorites, comes into our air and gives us the appearance of falling stars, and probably also the occurrence of a fall of a meteorite or two, —what would most probably be the source of the luminosity? As a matter of fact what we do see when these bodies enter our atmosphere and are rendered incandescent by arrested motion, in the manner which I have already referred to, are spectroscopic indications of the existence of sodium. The bright yellow of a falling star is due to incandescent sodium vapour, sodium being that among the elements of all meteorites which is most volatile as a metal. Next after that, in the cases where brilliancy is extreme, and where the yellow colour of the falling star gives place to brilliant white or even to a dazzling bluish white, we get added to sodium indications of magnesium. And after that, in the case of falling stars brighter even than those which I have already supposed, we have added to the sodium and the magnesium unmistakable traces of iron vapour. Now this shows us very distinctly that if—I say if—according to this hypothesis, we really do get as falling stars what we get as the head of a comet, the temperature of a comet is much less than the temperature of the falling star while it is passing through our atmosphere, because in the comet we only get a temperature high enough to render the most volatile constituent, hydro carbon, incandescent, whereas we have passed that stage altogether when the meteorite comes into our atmosphere and the incandescence of hydro carbon is replaced

by the incandescence of magnesium, sodium, and iron vapours. There is, therefore, abundant proof on this hypothesis that the temperature of a falling star, when it is passing through our air, is higher than the temperature of that same mass of matter when it formed part of the head of a comet.

There is one point to which I think I may be permitted to draw your attention, although at present it rests merely upon an unendorsed observation of my own. I thought it would be worth while to try what would happen if I enclosed specimens of meteorites, taken at random, in a tube from which I subsequently exhausted the air by a pump. After the pumping had gone on for some considerable time, of course we got an approach to a vacuum; and arrangements were made by means of which an electric spark could pass along this apparent vacuum, and give us the spectra of the gases evolved from the meteorites. Taking those precautions which are generally supposed to give us a spark of low temperature, and passing the current, we got a luminous effect which, on being analysed by the spectroscope, gave us that same spectrum of hydro-carbon which Mr. Huggins, Donati, and others have made us perfectly familiar with as the spectrum of the head of a comet. There then we get the atmosphere of meteorites, not necessarily carbonaceous meteorites, but meteorites taken at random; and this atmosphere is exactly what we get in the head of a comet.

Now let me go one step further; and to take that step with advantage, allow me to refer to another point noticed in the last lecture, which was this—that whereas Schiaparelli had connected meteorites and falling stars with comets, Professors Tait and Thomson, on the other hand, had connected comets with nebulæ, both of them being, according to those physicists, clouds of stones. Now how was one to carry these spectroscopic observations into the region of the nebulæ? A Leyden jar was included in the circuit, and we had what is generally supposed to be an electric current giving us a very much higher temperature than we had before. What then was the spectrum? The spectrum, so far as the known lines were concerned, was the spectrum which we get from the nebulæ; for the hydro-carbon spectrum, which we get from the atmospheric meteorites at a low temperature, was replaced by the spectrum of hydrogen; the spectrum of hydrogen coming of course from the decomposition of the hydro-carbon, with the curious but at present unexplained fact that we got the spectrum indications

of hydrogen without indications of carbon. In my laboratory work I have come across other curious cases in which compound vapours when dissociated only gave us one spectrum at a time—by which I mean that in a vapour consisting of two well-known substances, under one condition we only get the spectrum of one substance, and under another condition we get the spectrum of the other substance alone, so in others again of both combined. The evidence seems therefore—though I do not profess to speak with certainty—entirely in favour of the ideas of Sir William Thomson and Professor Tait on the one hand, and of Schiaparelli on the other. I note this because I shall have again to refer to the conclusion to be drawn from it, namely, that there is probably an intimate connection between nebulæ, comets, meteorites, and falling stars.

The Stars.

Concluding what I have to say with regard to the first great group of the heavenly bodies, namely, that group which we can study by means of the radiation of light apart from absorption, I will now take up the next class, consisting of those bodies which we study by absorption.

What do I mean when I say those bodies which we study by absorption? I mean this—that whereas in the case of the radiation of light the vibrating molecules directly communicate with us and set in motion the ether which ultimately comes to our eyes; in absorbing bodies, on the other hand, the vibrations which we study have been set in motion not directly, but by the intrinsic vibration of other bodies further from us and more violently agitated than the vapours themselves, In other words, if you assume a mass of matter which is competent to give you every wave length of the spectrum—that is to say, a continuous spectrum, and if you assume around it individualised vapours at a lower temperature, those vapours, although they cannot be studied by their radiation, if they are not hot enough to allow their lines to be seen as bright lines on the bright background of the continuous spectrum, can still be studied by their absorption, because they are made to vibrate by those wave lengths given off by the interior mass passing through them with which they can synchronise. Therefore we pass from those celestial objects which we study by

means of their bright lines, to those other bodies which we study by their dark lines ; we pass from radiation spectra to absorption spectra.

What bodies in the skies then can we get at by this means ? We have already, by means of radiation, been able to gather several secrets from nebulæ and from comets, which are the objects which we can study by means of their radiation alone. The most numerous class of bodies in the universe, so far at

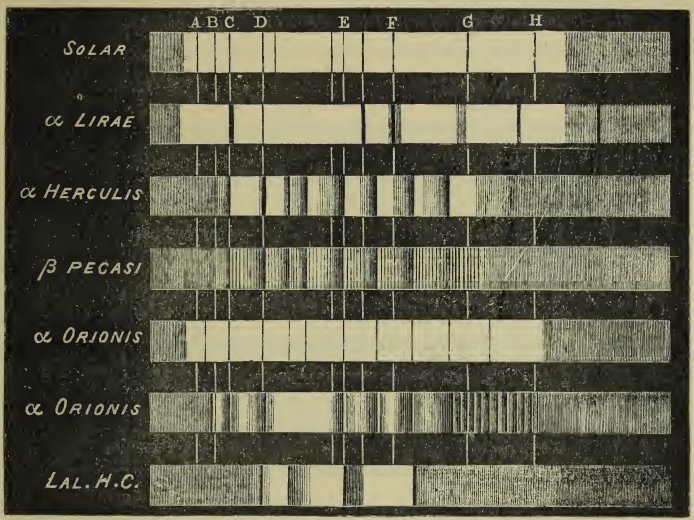

FIG. 11.—Various types of stellar spectra.

all events as we are able to grasp the universe, are what we term the fixed stars, including, of course, our sun.

In order to make my meaning quite clear, I will throw upon the screen a drawing which we owe to Father Secchi, which will give you at one view several typical spectra of the fixed stars. When we pass from the nebulæ and the comets we pass from bodies which have almost identical spectra in each case to bodies in which the spectra are very different. This diagram shows us the different classes into which the series may be grouped the moment we put this spectroscopic question

to them: What lines have you in your spectrum? or What channelled-spaces have you in your spectrum? We have at the top, you see, the spectrum against which is written the word "solar;" and that means that we have there in our sun a representation of a large number of stars, which, be it also remarked, may be large or small, for this classification apparently does not hold good for the different magnitudes.

Then, again, we have a spectrum which is common to a great number of the most brilliant stars in the heavens; and the difference between that spectrum and the upper one is that it has a much smaller number of lines, and that these lines are thicker. Another spectrum is somewhat like the solar spec-

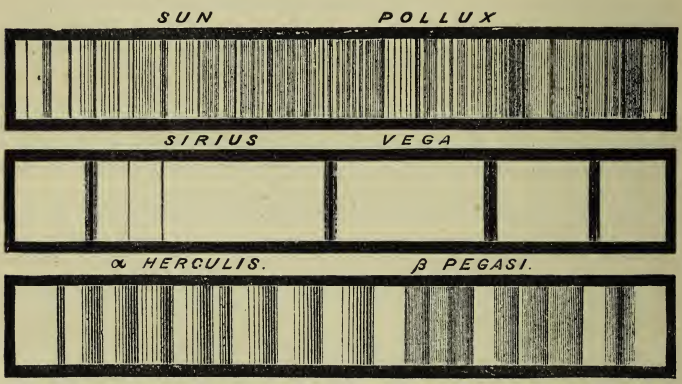

FIG. 12.—The three chief types of spectra seen in more detail.

trum, so far as the number of lines is concerned, but some of the lines do not agree in position with the lines in the solar spectrum. Now, in the three spectra to which I have already called your attention you see that we have unmistakable line-absorption; and, in the light of what I ventured to bring before you in the last lecture, I hope you will quite understand that we have evidences in the atmospheres of those stars that the elements are broken down to their ultimate degree of fineness. But when I call your attention to the other four stellar groups, you will find it is no longer a question of line-absorption; instead, indeed, of a spectrum, resembling the spectrum of calcium and iron, which I showed

you in the last lecture, we have now most distinct channelled spectra, which will remind you of that beautiful photograph of carbon. That carbon vapour we know was more complicated than the calcium vapour and iron vapour with which it was mixed. We have then, so far as this diagram can show us, different kinds of absorption going on in the stars; so much so, that we can divide the stars into groups, first, according to whether or not their absorption is the line-absorption or the channelled-space absorption; and then, again, according to whether the absorption is indicated to us by many thin lines or by few thick ones. I have another diagram here which will enable us to go somewhat more into detail. This diagram we also owe to Father Secchi. It

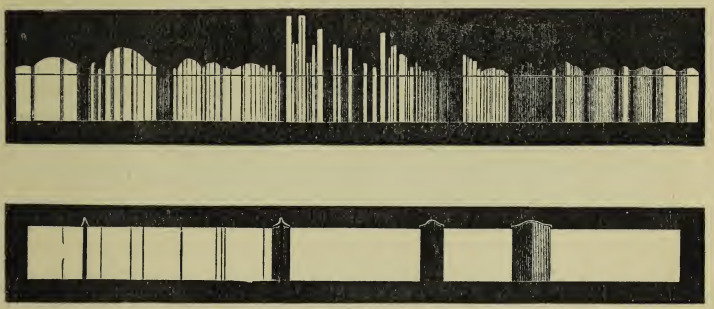

Fig. 13.—Spectrum of α Orionis compared with that of Sirius.

shows you with what extreme care this kind of observation has already been commenced and what detail has already been acquired. We have in the upper part a drawing of the spectrum of α Orionis, from which you will gather that the first drawing which I brought to your notice was only intended to give you the generic differences between the star classes, and not the special differences. Difference between a star of the type of the sun and of a star of the type of Sirius becomes much more clear and definite when we have the opportunity of observing the enormous number of lines in the stars of the sun type and the comparative freedom from lines of the stars like Sirius and Vega. In order to enter still further into detail in the case of the nearest star, I

will throw on the screen a photograph of a large part of the solar spectrum, which we owe to Mr. Rutherfurd of New York. This will indicate to you the extreme importance of getting the sun to do as much work for us as it can in the way of recording its own chemical constitution by means of photography. This photograph is on such a scale that in order to include a small portion of the spectrum it has been necessary to give it in five successive strips, the less refrangible lines being to the left at the top, and the most refrangible to the right at the bottom. Now, the chemical constitution of the sun and stars, so far as the detail is concerned, consists in finding out, as I am sure you all know, to the absorption of what particular element each of these lines is due. Now there, for instance, in the line F, we know that we have to do with hydrogen. We know that in the line near

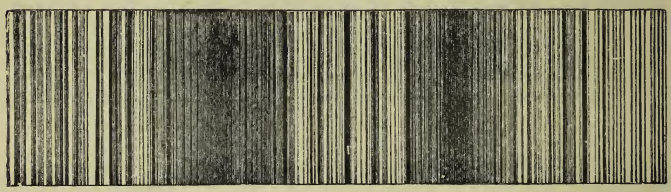

Fig. 14.—Copy of a photograph of the solar spectrum in the region of the thick calcium lines, by Lockyer.

G we have to deal with hydrogen again, and that a great many of these very complex lines about G are due some of them to iron, some to calcium, and some to strontium, and so on. Coming to the extreme limit of the visible spectrum, we find lines thicker than all the rest, and those lines we know to be due to calcium. The reason those lines are apparently thicker than all the rest seems to be that probably there is more calcium than anything else in that particular part of the sun's atmosphere where this absorption takes place.

Now that remark opens up the kind of inquiry which is possible to us when we wish to inquire into the chemical constitution of the stars. We have the position of the lines, the number of lines, and the thickness of the lines; and, let me add, when we get definite evidence of change, we want to know the change in the thickness of the lines. Now, when

we come to deal with the first class of stars, the brightest and the bluest in the heavens—stars such as Sirius and Vega—much brighter and probably therefore hotter than our own sun—we deal with the extremest simplicity of chemical constitution. We seem to be dealing almost entirely with hydrogen alone. I say almost entirely, because there appear in the best instruments traces of sodium and magnesium—those metals we have already been familiarised with by our reference to meteorites—in addition to the hydrogen; but that simplicity of construction of the spectrum which you saw on the screen, and the thickness of the lines, taken in connection with the position of those lines, indicates to us that the atmospheres of those stars are composed to very great extent of hydrogen.

When we pass to the stars of the second class, such as our sun, the chemical complexity is very much greater. If we take the sun as a type of stars of the second class, many of the elements present in its atmosphere have been determined with almost absolute certainty:—

TABLE OF ELEMENTS IN THE SUN.

Coronal Atmosphere	1474 stuff (new element ?) Hydrogen, sub-incandescent.
Chromosphere . . .	Hydrogen, incandescent Helium (new element ?) Calcium Magnesium.
Spot Zone	Sodium Titanium Chromium ? Aluminium.
Reversing Layer .	Iron Manganese Cobalt Nickel Copper Zinc Potassium Strontium Barium Cadmium Lead.

Besides which there are indications that other metals may soon be added to the list, vanadium for instance. The stars then

of the second class, of which our sun is one, have atmospheres composed of these elements. Here, as in the case of the meteorites, our knowledge is already great and is rapidly increasing; but when we come to the red stars, to the stars which give us channelled-space absorption, there up to the present time our knowledge has been extremely limited. We have not been able to study the molecules of elementary bodies and compound bodies under those conditions at which they give us the channelled-space spectra to such an extent as we have been able to study them under those conditions at which they give us line-spectra. The result is therefore that when we come to the third class of stars with these channelled spaces, science at the present moment recoils, and is compelled to say that she does not know of what the atmospheres of these stars is composed. But again, in the light of the photograph which I showed you in my last lecture, we can come to certain very definite ideas. For instance, we have no difficulty in coming to the conclusion that the star in which we get the channelled-space absorption must be cooler than the star in which the absorption is of the line kind. It is not at all impossible that science, by taking an entire survey of the whole of space, may, in not a very long period, be in possession of such facts as apparently she could only have acquired by having been present in all points of time; we may get, in fact, from different regions of space, conditions which have happened to the same body at different epochs of time; and already it is not, I think, too much to suggest that when we get a star with a channelled space absorption we have got a cooling star, the absorption of which must once have been of the line kind; therefore the stars which now give us line-absorption as they get cooler must give us channelled space spectra, and so on till they become dim and cease to give us light altogether.

All of you, I am sure, have been struck, one night or another in your lives, with the exquisite colours of some stars. There is no sameness in Nature. The colours of the stars are not so well seen in Manchester or in England generally as they are in the tropics and in more favoured lands; but still we do, if we take the trouble, easily see evidences of the most beautiful coloration amongst these celestial bodies. Nor is this all. More careful observations of the stars make it absolutely clear to us that they vary very much in the light which they give out; and it is also known that the variation

of colour may go on *pari passu* with the variation of their light. We owe the first important suggestion on this point to Angström, who showed that if in the atmosphere of a star we imagine the molecules at what we may term the critical point, and suppose them to be in a condition of heat which enabled them to give the line spectrum, and also near that reduced temperature and possible association at which they could give the channelled space absorption, a very small reduction of temperature would at once change utterly the amount of light given out by that star. For instance, if you assume that stars of the third class were once stars of the second, we know that if the change could have taken place suddenly, it would have appeared as if these stars lost a great deal of their light, and that the yellow light was gradually changed to red. Now the variability of stars can go to such an extent, as I have already hinted, that a star will go out altogether, so far as our powers of seeing it are concerned. And again we may perceive a star in a region of the heavens where a night before no brilliancy was visible. How can we account for this? So far as the physics of the stars are concerned, the merely chemical considerations would at once explain to you how it was that a star should by and by lose its light. The cooling of the atmosphere, and the consequent increased absorption of the molecules of that atmosphere, as they got more complicated by the reduction of temperature, would be quite sufficient to stop all light which came from the nucleus. When we inquire how it comes that a star may suddenly shine out where no star ever shone before, there the law of uniformity, the law of continuity, does not come to our rescue so well as it does in the first case. We do want there something like a catastrophe. You recollect that a few years ago Dr. Huggins was enabled to make a most important series of observations on a star which broke suddenly into intense light and then faded away into the utmost bounds of visibility. Now there it was found that the light of the star, changing as it did, gave rise to perfectly different spectrum effects. That star when it was only of a certain definite brightness, as it was at first seen, gave us a spectrum with dark lines similar to those I have thrown on the screen; but when its maximum brilliancy was reached, the character of the spectrum changed—a spectrum of bright lines was added; and then we had an indication of a new class of bodies, namely, those bodies which we study both by their radiation and absorption. So much for the facts.

The Sun.

We will now pass to the sun, so that we may be able to build any conclusions with regard to the causes of these phenomena in the case of the more distant bodies on somewhat firmer foundations than we could have done had we not this big star close to us to refer to. In the first place, I would like to show you that the statements which have been made with regard to the chemical constitution of the stars rest upon a basis sufficiently firm to justify me in bringing them before you. Dr. Huggins, who was the first to observe the spectra of the stars in a manner which left nothing to be desired, so far as eye observations were concerned, made comparisons of the dark lines of the stars with the bright lines of the different elements in the same instrument at the same moment. A very small addition to that method, namely, the introduction of photography, enables us not only to do this, but to make a record which is good for all time. I propose therefore to illustrate the method by throwing upon the screen two photographic comparisons, the object of which was to determine which were the lines I have already shown you in the solar spectrum, which were really due to the vibration of the particles of iron vapour in the atmosphere of the sun. For that purpose all that one had to do was first to photograph the spectrum of the sun, and then on the same plate and by the same instrument, under absolutely the same conditions, photograph the spectrum given by the iron vapour. You will see the result on the screen. Of course such a photograph has to be made for every chemical element the existence of which in the sun we wish to study. I may remark, in passing, that the only difficulty in illustrating this kind of inquiry is the impossibility one labours under of ever getting a chemical substance which is absolutely pure. We have now on the screen, on a very large scale indeed, that part of the solar spectrum which in Mr. Rutherfurd's photograph was to the extreme right at bottom. Here are the two calcium lines which you saw before, and which are much thicker than any other lines in the spectrum. The dark lines are the regions where there is no light to paint the image of the slit in consequence of that light having been absorbed by the iron vapour in the atmosphere of the sun; and above these dark lines you have the images of the slit painted by

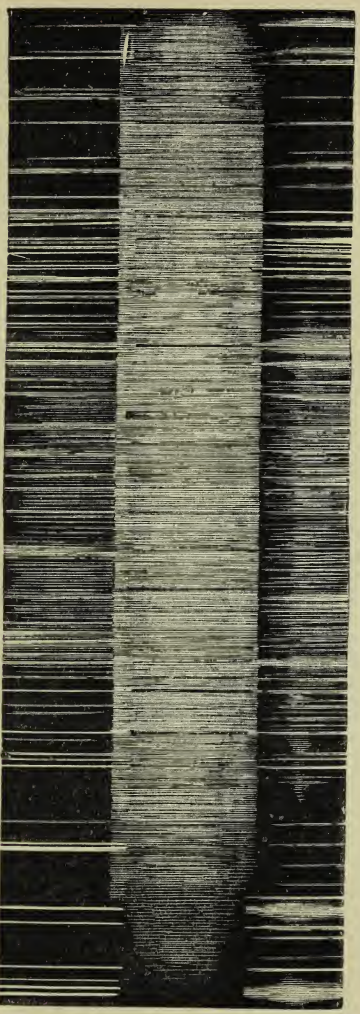

FIG. 15.—Comparison of the absorption spectrum of the Sun with the radiation spectra of iron and calcium, with common impurities. Copy of a photograph by Lockyer.

the vibrations of iron vapour, not in the sun's atmosphere, but in a laboratory at South Kensington. If you will take the trouble to compare the more definite lines you will see that there is a perfect coincidence between the bright lines and the dark ones which are caused by the iron vapour of the sun.

The next diagram [1] is, if anything, more interesting still. In this one we are dealing not with iron but with manganese. We have, you see, bright lines coincident with the dark lines of calcium, but these are due to calcium impurities. I am anxious to call your attention to a group of four lines in the solar spectrum and a broad band of light, corresponding with these in the spectrum of manganese. There are three bands of absorption on this band exactly coinciding with the three more refrangible lines in the solar spectrum to which I have drawn attention; that is to say, we not only in that photograph get absolute proof that those four lines in the solar spectrum are due to absorption at the sun by vapour of manganese, but we get the vapour of manganese in a laboratory doing for the more incandescent manganese what the outside sun does for the inside sun; we have in fact the cool vapour of manganese around the incandescent manganese giving us *nearly* the same absorptive effects as the manganese vapour does at the sun.

So much then for the method of acquiring these chemical facts. If we merely had that method, we should be able to say that certain substances exist in the sun; but that would scarcely be enough. We don't want to know merely that such and such substances exist in the sun or in a distant star; if possible, we want to know whereabouts in that star the particular substance lies. Now for that purpose we have to consider these spectroscopic results in connection with the telescopic results. What I mean by telescopic results will be brought before you by throwing on the screen in the first place a photograph of the sun which again I owe to the kindness of Mr. Rutherfurd of New York. Here is the sun on an enormous scale, photographed by itself.

The Chemistry of Different Portions of the Sun.

Now if instead of observing the sun as ordinarily visible, we observe it during an eclipse, we find that the sun that we see is only the small interior nucleus, so to speak, of the true sun.

[1] This photograph is not given, but the same effect may be noticed in Fig. 1 in the case of the thicker lines of calcium and aluminium.

and the reason we see the interior nucleus alone is because it is so very much more bright than the surrounding atmosphere. This photograph (Fig. 16) was taken in India in 1871. When we get the dark moon exactly between us and the brighter interior sun, there is no difficulty whatever in seeing that there is an atmosphere with its own characteristic effects, extending to a considerable distance above what we consider the sun ordinarily speaking (Fig. 17). So that you see telescopically we can make a complete distinction between one part of the sun and the other.

Now the question is, can we spectroscopically determine in what particular part of the sun each of these elements exists?

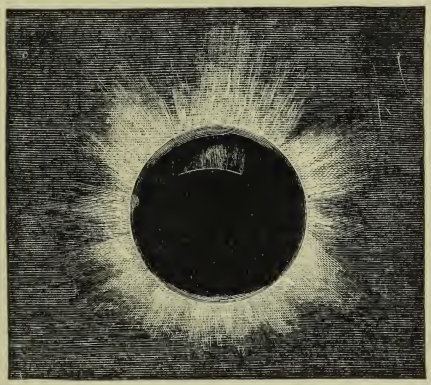

FIG. 16.—The Sun's corona, from a photograph taken in 1871.

Here is another drawing, which shows you what happens when we observe the region intermediate between the two I have shown you. The first drawing brought before you the photosphere of the sun; the second drawing brought before you the corona—the name given to all the exterior of the sun. At the base of the coronal atmosphere, that is, just above the photosphere, we have a region which has been named the chromosphere, in which certain strange forms are to be seen, and which are here shown (Fig. 18) from a drawing by Professor Young. These have been called "prominences," or "red flames."

So that we have the photosphere underlying part of the sun's

atmosphere and above all the coronal atmosphere ; resting in the middle, so to speak, this chromosphere and its prominences ; and then between the photosphere and the base of the chromo-

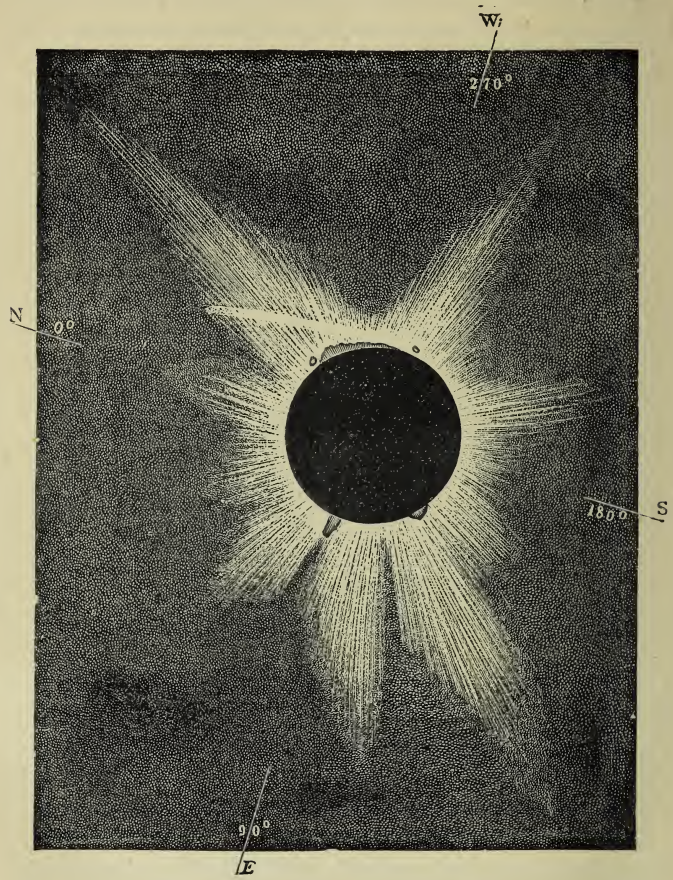

FIG. 17.—The Sun's corona and prominences, sketched during the eclipse of 1868.

sphere an extremely thin layer where most of the absorption takes place. Now this thin layer has been called the reversing layer, because it is here that the sun's light is reversed and

the Fraunhofer lines produced ; so that the statements generally made as to the chemical constitution of the sun and stars really refer to this particular film—for film it is, in comparison to the size of the sun—lying between the chromosphere and photosphere. We have, therefore, the photosphere, reversing layer, chromosphere and coronal atmosphere, into which, if we can, we may sort out the different elements.

Now this is what has been done, and the results are shown in the table (page 31).

If you imagine an arrow shot into the sun, it would first pass through the unknown element of which the upper part

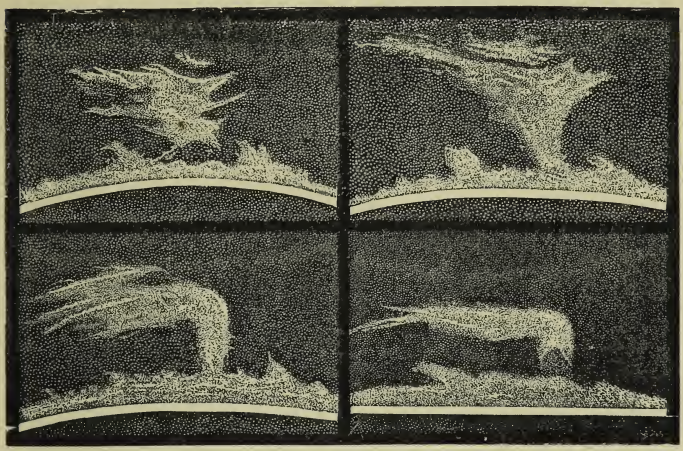

Fig. 18.– Young's drawings of prominences.

of the coronal atmosphere seems to be chiefly composed ; it would then come to the region where practically there is hydrogen and nothing else ; getting into the chromosphere you come to another new element, and then in the reversing layer you get magnesium, calcium, sodium, &c. At length we come to traces of some substances which either exist there in very small quantities or lie at a much lower level than the others.

For one of the important teachings of this work seems to be that at the great temperature of the sun—a temperature which brings about a dissociation much more complete than

anything we can obtain here even by electricity, unless perhaps we use the most powerful induction coils—there is the same magnificent order, though it may not be fully known, which exists throughout nature, and we find hydrogen thinning out at one level and magnesium thinning out at another, and so on; and I have suggested that the system of strata produced by this thinning out may be connected with the true vapour densities of the elementary bodies.

With regard to magnesium and calcium, I should remark that the list, made in 1874 will most probably have to be revised, as one of the results of the Eclipse Expedition to Siam in 1875;[1] for although in all past work on the sun it was impossible to determine whether magnesium or calcium was highest, the Siam observations seem to add to the probability that calcium really lies above magnesium; in other words, that the true vapour density of calcium is less than the true vapour density of magnesium. This reference to vapour densities will in the next lecture bring me into complete *rapport* with Professor Roscoe's lectures on the chemical structure of the earth's crust.

The Planets.

There is still, however, another large group of bodies to be considered—I refer to the Planets—before we have exhausted the bodies external to the Earth. Although, however, this group of bodies is numerous, we have not very much to say about them, for a reason which I am sure you will easily appreciate. When we deal with the radiation of the heavenly bodies, we are dealing with a condition of vibration of particles of those bodies at their utmost fineness, so that each vibration comes to us with a story to tell as to the actual chemical constitution of that body. Then when we come to that large class of objects which we study by means of absorption, there again we have the same molecules doing the same thing, but instead of giving us vibrations of their own, they absorb other vibrations which were attempting to pass through them. But when we come to the planets, we come to bodies like our own earth; bodies comparatively cool; bodies not in a state of incandescence, where matter is not as a rule in a state of gas or vapour, but

[1] I have done this in the table as given.

in the solid form. We come therefore to bodies which can neither radiate nor absorb light, in the sense in which we have dealt with radiation and absorption; because, in consequence of the reduction of their temperatures the chemical elements have compounded; we have not the individuality which is requisite; we have not the discrete particles, but combinations of every complexity. As the result of that, what is our only chance of seeing them at all? We see them by reflected light. The bodies now under consideration, unlike the nebulæ and comets, and unlike the stars, reflect light to us, and only by the reflection from their surfaces can we tell that they exist. Now as all bodies, whether they are solid or liquid, are spectroscopically dead, so to speak, so far as getting chemical information from them is concerned, inquiry is perfectly useless excepting in one particular—it proves that it is powerless, by showing that the light of the sun is so faithfully reflected by these bodies, that all the principal lines of the solar spectrum are to be found in it. It is true that there are exceptions in the case of the exterior planets of our system, especially in Uranus and Neptune. In the spectrum of those bodies, cool though they are, like our own, in addition to a constant absorption of the sun's atmosphere and the earth's atmosphere, a third absorption of the atmosphere of the individual planet is indicated. With that exception, you will see that the spectroscope is powerless to help us. How then can we hope to get at the chemical constitution of the planets if the spectroscope does not come to our assistance? There is, I fear, only one chance for us, and that is to determine, as nearly as may be, the densities of these bodies, and to see if it is possible to find out anything to reason upon when these densities have been thoroughly well sifted. Now we do know already with some accuracy the density of the planets. We know that these planets may be broadly divided into two groups; we have the interior group, of which the Earth is one—Mercury, Venus, the Earth, Mars—small heavy planets. The density of the earth is about five and a half times the density of water. The density of these interior planets you may say, roughly, is the same as the density of the earth; therefore we have this group of interior planets with a density of five and a half times that of water. After this we have a considerable gap, a gap partly filled by the minor planets or asteroids; and after that we get another group—Jupiter, Saturn, Uranus, Neptune—not small and dense planets like the Earth, but enormous

light planets, having, roughly speaking, and on the average, about the density of water. So that the density of the interior planets is to the density of the exterior planets about as five to one. Now if this density were known to be associated, in the case of the planets I have named with equal solidity from centre to circumference, of course we should be able then to form a rough idea as to their composition. But we do not know that. But still let us, if we can, carry the inquiry into the secondary bodies of this system—into their satellites.

If we take the only case in which facts approximately accurate are at our disposal—the case of Jupiter—we find that if we take the density of the satellites of Jupiter to be on an average one, the density of Jupiter is five, and the density of the Earth as an interior planet would be twenty-five ; so that the outside planets of our system are one-fifth the density of the inside planets ; and in the only case where we have a complicated system of satellites, that we can deal with, we have exactly the same relationship there, and the satellite is only one-fifth of the density of the planet itself.

I hope to have the opportunity next week of pointing these remarks by reference to what I have already brought before you, especially to the condensation of the nebulæ and to the particular position which each chemical element occupies at the present moment in the atmosphere of the sun.

LECTURE III.

In the latter part of the last lecture I referred to the different densities of the two great planetary groups. We saw the interior group of a density, roughly speaking, five times greater than that of the exterior group; and taking the satellites of one body in the exterior group, we found the same relationship of density; the primary being five times as dense as the secondary body, which in that case was one of the satellites of Jupiter.

Now the fact that the Earth is one of the interior group of planets leads us to assume (and I pointed out to you that assumption is almost the only thing left to us in regard to estimating the chemical relationships of the earth) that probably the chemical constitution of the earth is similar to that of the planets which form the interior group—Mercury, Venus, the Earth, and Mars. Now if we look upon the planets from another point of view, if we consider the extent to which some of them are flattened at the poles, we find the same grouping as we did before. The interior planets are flattened very little at the poles, as compared with th flattening of the exterior bodies. Now this flattening has been very beautifully experimented upon by Professor Plateau; and, thanks to Mr. Binyon's skill, I hope I shall be able to throw on the screen some of the phenomena to which Professor Plateau refers. When it is a question of investigating the flattening of a planet experimentally, the first thing one has to do is to take away the influence that gravity might have on the body experimented upon; and Professor Plateau very ingeniously did this by making the rotating body a mass of oil in a mixture of spirit and water of precisely the same specific gravity; so that the mass of oil in the centre was neither inclined to rise nor fall, if the mixture had been

properly made. Here we have on the screen an image of such a mass of oil and a disc connected with a spindle, which we can cause to revolve somewhat rapidly. The revolution of the spindle is communicated to the oil by means of the disc, and what we find is this (supposing the experiment to be perfect). With a certain amount of rotation, the spherical form of the oil first changes into a spheroidal one; as the rotation is increased we get a flattening—as the mass of oil is compressed in one direction it is extended in the other—and we get the equivalent of what we have in the Earth which we describe by saying that the equatorial diameter is so much greater than the polar diameter. When we are able to repeat this beautiful experiment under the best conditions, we find that after a certain point, the oil is not content with expanding in one plane; it is not a question of shortening one diameter and increasing another, but under one set of conditions the oil can be made to form a complete ring, absolutely perfect and disconnected from the central disc; and when the rotation of the central disc is slackened, the oil then comes back again and re-forms, so to speak, a miniature planet. That is one case. Another case can be studied by commencing the rotation with somewhat greater rapidity; and what happens then is that, instead of getting the formation of a ring, the oil is broken up and thrown off in tangents, forming a kind of spiral. Those are the two main classes of phenomena which can be observed in this way.

The interior group of planets has a day almost entirely the same as ours—a period of rotation of about twenty-four hours. The period of rotation of the exterior planets has not been determined in the case of the two exterior ones, Neptune and Uranus; but we do know that in the case of Jupiter and Saturn the rotation is accomplished in less than half the time taken by the members of the interior group.

What, then, are the facts with regard to these planets and their flattening? I am able, by the kindness of several friends, to throw upon the screen some very beautiful drawings of all the planets which I have mentioned; and I want you to be good enough to look at these drawings from two or three points of view. First, I want you to see the difference in the amount of the polar compression in each case; and, for future reference, also the difference in the atmospheric effects. We will begin then with the planet which is most similar to our own, the planet Mars.

You will see that it has markings similar in kind, no doubt,

FIG. 19.—Mars; south pole visible.

FIG. 20.—Mars; both polar caps visible.

to the markings which would be seen by the spectator observ-

ing the Earth from the Moon. You will see also that its compression is small—in fact, I may say, that it is not to be appreciated at all. Here are three drawings of Mars, made by the distinguished Dutch astronomer, Kaiser, of Leyden. You see that there is no polar flattening. That the upper part represents the true pole of the planet is rendered evident by the fact that you have there a snow cap at the south pole. There again you have the snow cap ; and here in these dark markings we have seas. The Earth's place then, in Nature, both as to polar compression and atmospheric condition, is evidently very similar to that of Mars. When, however, we go

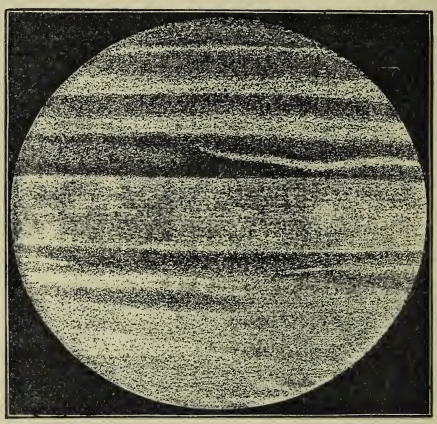

Fig. 21.—Jupiter.

from Mars, which is the only member of the interior group, excepting the Earth, about which we can say anything with decision, we see that all the phenomena are considerably changed. We pass from a density of five to a density of one, and the twenty-four hours day or thereabouts of Mars is now replaced by a day of something like ten hours in the case of Jupiter, the planet which comes next in our survey. Here we see how much shorter the polar diameter is than the equatorial one. You will be reminded by these cloud-belts of the much more simple system of cloud-belts which traverses our own Earth near the equatorial regions. There is little

doubt that the darker portions here are the portions of the atmosphere of the planet freest from cloud, and it is especially in this region that an observation to which I shall presently have to refer was made. Going then still outwards, we come from a compression of considerable magnitude to a planet in which the compression is somewhat less. But you will see, that although the polar compression is somewhat less, we have what I termed an "extreme case," when I was referring to Plateau's experiment. We have in the planet before you (Saturn) exactly the condition which was observed by Plateau in his experiments with the oil and mixture of spirit and water. We have traces of clouds, as in Jupiter; but the all-absorbing feature in the case of Saturn is this wonderful ring, about which observations are, fortunately for science, being very rapidly accumulated, showing that considerable changes are going on in it.

We now know that we are in presence of a ring, or rather an infinite series of rings, of, let us say, meteorites, small satellites of Saturn, out of which at some future time larger satellites will be compounded. This is one of the most beautiful results of modern thought and work. Laplace, who first considered the question of the mechanics of the rings, which were in his time considered to be solid, was content to leave them solid, provided the rings were very numerous and that the centre of gravity of each was not coincident with the centre of gravity of the ball; but modern mathematicians, among whom must be specially mentioned Peirce and Clerk Maxwell, have shown that the rings cannot be solid and cannot be liquid, and in short such a structure as that referred to above is the one now required by mathematical theory. Such a structure, moreover, is the only one which fits the facts. The brightness of different portions, the variations in brightness and breadth of each bright or dark part, the gradual widening of the whole system—29 miles a year according to one estimate—and many other facts are thus easily explained. Some recent observations[1] made by the Washington 26-inch equatorial not only establish important changes which have recently been going on, but afford further evidence of the meteoric structure of the strange appendages, *e.g.*, the dusky inner ring is not now perfectly transparent as it once was, the planet can only be partly seen through it, while the matter composing it is agglomerated here and there into small masses, which prevent the planet being seen. Mottled

[1] Trouvelot, Proc. Amer. Acad. 1876, p. 174.

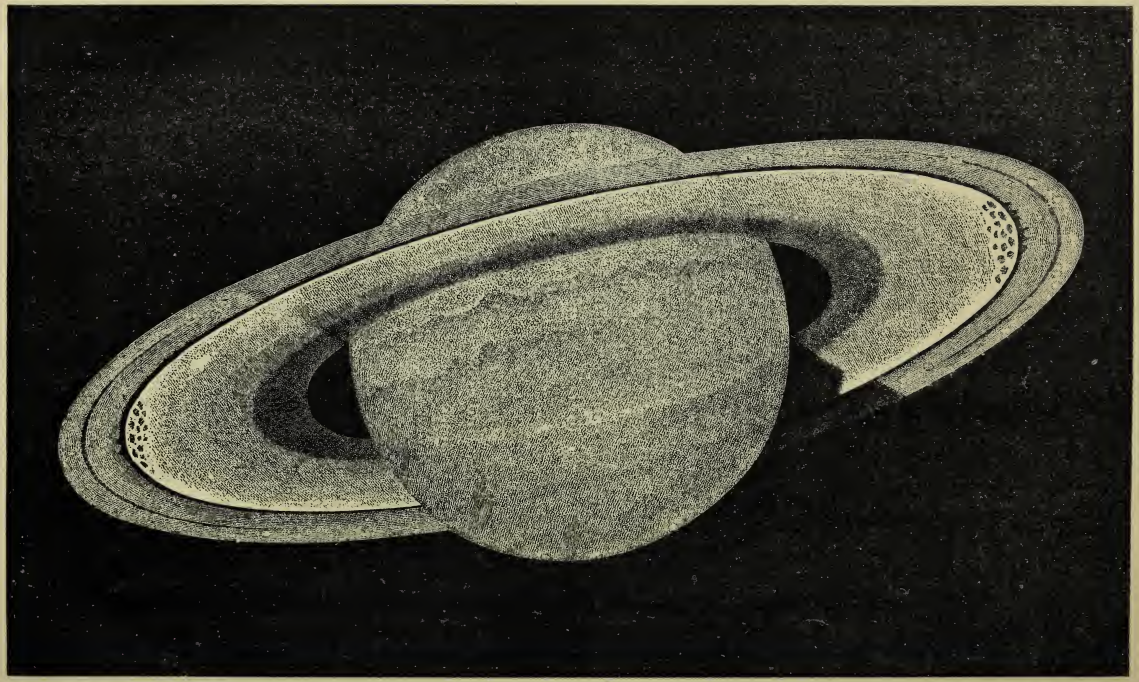

Fig. 22.—Saturn, from a drawing by Trouvelot, made by the Washington 26-inch refractor.

or cloudy appearances have also been observed on the surface of the exterior portions of the ring system during the last four years.

We must now pass from the facts relating to the physical condition of the two great groups, as it is as yet impossible by a further discussion of them to learn anything about the chemical constitution of the planets themselves. The question arises—Can we learn anything about the composition of their atmospheres? Let me remind you that we are dealing with that class of bodies which shine by reflected light. It is clear therefore that when we examine by the spectroscope the light of the sun reflected by these bodies, we shall have the solar spectrum, *plus* the spectrum due to the absorption of any special planet. Now, as a matter of fact, the solar spectrum, as observed from the Earth, is tainted by, or mixed up with, the absorption of our own atmosphere. But fortunately we can get rid of the absorption effect of our atmosphere by varying the observations so that at one time we shall have a great thickness of atmosphere, as when we observe the sun in the morning or evening, and at other times a small thickness, as when we observe at mid-day; and at those times we shall have the spectrum changed, owing to this change of condition. In that way men of science have been able to separate the absorption taking place at the sun, from the absorption due to the Earth's atmosphere.

The interior planets tell us that there is absolutely no special absorption in their atmospheres. So far as they have atmospheres at all, they are undoubtedly similar to our own; therefore the Earth's place in Nature is with the interior groups of planets. But when we pass outwards from the interior group to the uttermost confines of the exterior one, when we leave Mars to go to Neptune, Saturn, and Uranus, we find that from Jupiter, outwards, there is a something interpolated into the atmosphere, so that the outermost planet has the atmosphere which differs most from our own. Uranus and Neptune have very extraordinary atmospheres of their own, which are indicated by a very definite spectrum. Traces of the substance which gives us this extraordinary absorption in the outermost planets are also to be found in the atmospheres of Jupiter and Saturn; so that we are driven to the conclusion that the atmosphere of the exterior planets is different from the atmosphere of the Earth by the addition of a new absorbing substance to the aqueous vapour which is the only *effective* absorber in our own atmosphere.

The Question of Evolution.

I have now gone through, *seriatim*, the physical and chemical constitution of nebulæ, stars and planets, so far as the facts and the time at my disposal have enabled me. What may we say then as a general summation of these facts, brought together with a view of determining whether they throw any light on the cause of the Earth's actual chemical constitution? Physically speaking, the Earth is a cooled body, revolving round an incandescent one. Chemically speaking, its chemistry has been most admirably brought before you by Dr. Roscoe in those three lectures which we have now the opportunity of reading carefully; and its kinship with the other bodies which people space has been established by the fact of the community of elements. Dealing only with the spectra which have been observed in the nebulæ we have recognized hydrogen; in the comets we have recognized hydrocarbons; in the stars and in the sun we can tell of elements amounting to twenty-five in the case of the sun, nearly all of which elements we have on this Earth; so that it is not too much to say that one of the glories of the spectroscope has been to show that the Earth in its chemical constitution is simply a part of one of the great systems of the universe, and differs in no way from the matter which masses here as nebulæ, there as comets, and there as stars.

I have drawn your attention to the conclusions which we are justified in drawing from the facts; and the question is, Does the story end now the facts end? I hope to show you that it need not necessarily do so. A student of science endeavours to accumulate facts. Facts are the rewards of scientific work; but how, when a man of science has accumulated a large number of facts, is he best to proceed to get new ones? That is our case. I have endeavoured to bring before you all the facts, roughly, which the spectroscope has placed at our disposal with regard to the chemical constitution of those different masses of matter which people space. But how are we to attempt to get more? Are we to go haphazard at it? No. Hypothesis is the life-blood of investigation; and having an array of facts before you, the thing to do is to attempt to put them in such an order that they will suggest inquiry in special directions. Do not be afraid when I say that hypothesis is the life-blood of investigation, lest the world should

soon be filled with hypotheses. History does not bear this out; and further, a man does just as good work by destroying an unsound hypothesis as by establishing firmly a true one. Having then these facts before us, and having necessarily to form some hypotheses, what is the most general question that we can put to these facts, which tell us of the existence of nebulæ, comets, suns, planets, and the like? The most general question, I think, that we can ask is such a one as this: Have we, as the result of our inquiry, got together such facts as enable us to consider nebulæ, stars, comets, and planets as finished products, each of them gloriously, magnificently, perfect in its way; or do these merely represent, let us say, the seed and the flower and the fruit?

Here, of course, we have to do with Evolution pure and simple; and I may remind you that it is now a good many years since two of the most profound thinkers on our planet at the time—I refer to the German and Frenchman, Kant and Laplace—independently arrived at the answer to the question I have propounded. The answer was identical, and it was this: You have in these various bodies not finished products, each perfect after its kind, but really and truly the seed and the flower and the fruit. And the hypothesis which they put forward was something like this—that the nebulæ, representing what I told you Tycho Brahe considered them to be—a true fire-dust—was probably wrought into stars by means of the condensation due to gravity, which in time brought the most irregular nebulæ down to the appearance and the consistence of a star. And then Laplace and Kant, knowing well of the observations of the rings of Saturn—the experimental imitation of which I have brought before you—suggested that our planets were left behind, first as rings, while the nebula was contracting to form a star. So that if you begin, in any quarter of space that you choose, with a nebula, and give it time to work, the nebula will condense, a star will be formed, and in the process rings, which will subsequently break up and form planets which will subsequently cool, will be produced. Such then is an hypothesis which has now been before the world some years and certainly is exceeded by none in the grandeur and grasp of its conception; it was started before the spectroscope, as we now know it, was dreamt of. Do the facts which have been brought to light by the spectroscope lead us to think that this hypothesis will no longer hold water now we have got a larger area of facts to deal with, or do the new facts really

come well in and support the old and enable us to fit other parts into it?

Now, in order to deal with this question, I shall first trace the passage from the nebula to the star, which is the first part of the conception of Kant and Laplace. If you will consider the conditions at work in a nebula such as I told you Professor Tait is content to imagine it, namely, a nebula consisting of a huge cloud of stones, the luminosity of which depends chiefly upon the impact of these stones together, and I suggest in part upon dissociation of hydrocarbon—if you take such a nebula as this, and imagine it to be condensed to a star, you will see at once that the conditions of Plateau's famous experiment are exactly reversed. In the experiment, we begin with the star at rest, and the experiment is performed by setting it in motion. But in truth, if Kant was right, that experiment must be exactly reversed; rotation will be at the end of the business. We must imagine rotation set up over an immense area, rapid enough, after the condensation in a plane is considerable, to give us many rings. What Plateau saw when the matter went outwards will occur backwards, as the matter condenses inwards. Instead of rings formed and moving outwards we shall have rings formed and moving inwards, tangential outpourings will be represented by tangential inpourings. I will recall your attention to two or three nebulæ, which I showed you on a former occasion, and in the light of this hypothesis, I think you will see that the telescopic evidence is also in favour of the idea. I am now about to show you the group of nebulæ sketched by Lord Rosse, some of them having been observed in the first instance by Sir John Herschel. I do not wish to call your attention to all of them, although much might be said, I am sure, about every one; but I want especially to draw your attention to those which resemble Saturn, and are like the sphere and ring of oil in Plateau's experiment. We have in the centre a condensation; we have around it a globular mass not so brilliantly illuminated; and around it again we have a ring. There again is an object of an almost similar kind, seen from a different point of view, in which the ring is edgeways to us. I might go on taking up very much more of your time, but I don't think it is necessary to enlarge very much upon this part of the subject, after the drawings I showed you on the first occasion. It will be clear to you that if we take this view we shall demand with each degree of

condensation, with each degree of contraction, an increase in brilliancy; so that the smaller the space occupied by the materials which first constituted the nebula, the brighter and the hotter will they become. So that we must imagine that the star finally formed must be one in an intense state of incandescence; in fact, in a state of incandescence of which we cannot have the most remote notion.

What says the spectroscope? Here the spectroscope is quite at one, I think, with the idea; in fact, there are nebulæ and stars with spectra so similar that if one had the evidence of the spectroscope alone, it might be impossible to decide which was nebula and which was star. Now this may be a little startling to some of you, and therefore it is only fair I should explain it. The stars, you know, are so remote from us that in the most powerful telescopes to which spectroscopes are applied, they appear only as the finest points of light. Now these points of light, it is not absurd to imagine, may in some instances be two millions, or perhaps even three millions, of miles in real diameter. We know that our own sun, which is certainly not the largest star in the heavens, is nearly one million miles in diameter; that is to say, the true sun, the true stellar nucleus, is one million miles in diameter. Now when I dealt in my second lecture with the physical constitution of the sun, I pointed out that the sun which we see, the sun which sends us the majority of the light we receive, is but a small kernel in a gigantic nut, so that the diameter of the real sun may be, say, two million miles. Suppose then that some stars have very large coronal atmospheres; if the area of the coronal atmosphere is small compared with the area of the section of the true disc of the sun, of course we shall get an ordinary spectrum of the star; that is to say, we shall get the indications of absorption which make us class the stars apart; we shall get a continuous spectrum barred by dark lines. But suppose that the area of the coronal atmosphere is something very considerable indeed, let us assume that it has an area, say fifty times greater than the section of the corona of the star itself; now, although each unit of surface of that coronal atmosphere may be much less luminous than an equal unit of surface of the true star at the centre, yet if the area be very large, the spectroscopic writing of that large area will become visible side by side with the dark lines due to the brilliant region in the centre where we can study absorption; other lines (bright ones) proceeding from the exterior portion

of that star will be visible in the spectrum of the apparent *point* we call a star. Now it is difficult to say whether such a body as that is a star or a nebula. We may look upon it as a nebula in a certain stage of condensation; we may look upon it as a star at a certain stage of growth.

And in the fact that we have actual nebulous stars—stars which in the telescope can scarcely be defined from true stars, and spectroscopic effects such that it is difficult for us to say whether they are produced by star or nebula, we have in these two points very strong arguments indeed in favour of this part at all events of the evolution hypothesis.

So much then for the passage from nebula to star. How about the passage from star to planet? Let us, in the first instance, assume that the nebula is vastly condensed before the rings begin to form. It is difficult of course for us to say whether this is really true or not, because we know not the distance of the nebulæ; but I think you will agree that it is a fair assumption. In this case, if the condensation is excessive, and the heat due to arrested motion be excessive also, we shall have then to deal with the facts. Where in the heavens have we just this particular series of facts? We have it in the sun. We have the sun now near to us, so that we can study its constitution, still in a state of intense incandescence, and so far as that point goes at all events it may be fairly taken to represent probably an earlier stage of its growth. And this being so, I think it will be fair to take the sun as representing the closest approximation to a nebula in its last stage which is available to us. It would be better perhaps if the line between the inner and outer atmospheres were less sharp, but we must take it as it is. Now one of the most unforeseen results connected with recent solar work has been that the different chemical substances which various observers have placed in the atmosphere of the sun, are not all mixed up pell-mell, but are really thinned out into layers; so that we can not only say, when we wish to compare the chemical constitution of the Earth with the sun, that the chemical constitution of the sun is so and so, but we can say that in the chemical constitution of the sun this element occupies one position in the solar atmosphere, and that element occupies another. So that, in fact, taking the sun to represent a nebula at the time that rings were being formed (mind you, I don't say thrown off, we must reverse Plateau's idea), the fundamental point we have to bear in mind is that if we take the sun at all, we must

take it with its layers. Now here we have an opportunity which Kant had not; and here, I think, the spectroscope enables us to deal with Kant's hypothesis in a somewhat satisfactory manner. We may be said to improve somewhat upon the conceptions which were merely physical by making them slightly chemical. Now if we have these known metals placed as near as may be in this order [Table]—probably the position of the metal aluminium is the most doubtful,—we have in the first instance to account for the absence of the metalloids. I have given grounds elsewhere, and it is not necessary to repeat them to-night, for believing that the most probable position for the various metalloids in the solar economy is outside these metallic strata. So that if we take a section of the sun's atmosphere, we must imagine the metalloids to be outside if they be there at all, and then as a link between the metalloids and denser metals, hydrogen, calcium, and magnesium generally coming in that order, or thereabouts. Let us for a moment consider the sun as a nebula. There is ample evidence, I think, to show that the temperature of the nebula was then as great as the temperature of the sun is now; consequently you will have all these metals existing uncombined, the metalloids existing outside, also probably uncombined. And what happens on Kant's hypothesis?—that the nebula in starting a rotation and contracting leaves behind it its exterior portion; so that probably we may say that the first planet thrown off—let us assume that that was Neptune, although probably there are many planets beyond Neptune—must have been thrown off from the extreme limit of such a nebula, and must have been built up of those particular materials which were existing at that particular part of the nebula; *that is to say, that it is almost impossible that there should not be an overwhelming preponderance of metalloid in Neptune.* As the various rings are formed from the exterior of the nebula while the contraction is going on, they will consist chiefly of metalloids; whereas when we come nearer to the sun, they will consist chiefly of metal. Now that being so, we have two opportunities of testing the idea which has led to this conclusion. If the exterior planets are metalloidal and the interior planets are metallic—(I do not mean that one group is *entirely* metalloidal and another *entirely* metallic)—it will be impossible for the density of the exterior planets to be as great as the density of the interior planets. We have already found out that that density, as a matter of fact, is about one to five.

This density, of course, must be lower, because we shall have the best possible conditions for high density where we get the metal in its purest state. Where the density then is least, in the case of the exterior planets, we shall find probably that the velocity of rotation will be different from the velocities of rotation of the other planets. That also, I have already pointed out to you, has been entirely answered by observation. Let us then, if we can, take this one step further. Let us take for granted that the difference between the interior planets and the exterior planets is precisely of this kind. Can we trace the same principle—can we send this chemical touch further into the hypothesis, and deal with, say, no longer the sun and the planet, but a planet and its satellite? I think we can; and I think too that in the case of Jupiter, the density of which as compared with the density of its satellites I have already mentioned to you, we have a most singular corroboration of the continuation of the sifting process.

If the facts I stated in the last lecture were accurate—and I believe they were as accurate as they may be in the present state of science—the density of the satellites of Jupiter in the main is only about one-fifth that of water. Now it so happens that one of the satellites of Jupiter, when it crosses the disc, very often puts on a very dark appearance. We have, therefore, here very good reason to infer that this particular satellite of Jupiter may probably be merely a mass of gas; and it is very possible that in the case of Neptune and Uranus we may be dealing with bodies which, for the same reason, will remain almost for ever in a semi-gaseous state. And let me remind you that this would at once explain the spectroscopic researches of Vogel and others on the atmospheres of these planets. If you have an atmosphere round Neptune and Uranus consisting of combined metalloids, we may have our choice between several possible spectra. I believe no one has yet made the direct experiment, but the description of the spectrum of Neptune given by Vogel is not very dissimilar from the spectra of the different oxides of nitrogen. That at once then would explain the various spectroscopic differences as well as the compression difference.

I must remind you, in order to make perfectly clear what I have already ventured to bring before you with regard to the form of these rings, that of course it is assumed that after the ring has been formed it eventually breaks up. Now the

facts, I think, seem to show that when this breaking-up takes place, a considerable amount of heat is produced; so that you see, if we consider the density of the exterior planets and their satellites, Jupiter, &c., and of our own Earth and its satellite, we have indications not only that this sifting, this sorting process, did really go on in the formation of the satellites as well as in the formation of the primaries, *but, because this process could go on at all, we have, I think, also additional evidence that there must have been a great amount of heat produced.* This heat is necessary to the hypothesis, both for the formation of the primary and the secondary bodies; because, unless you have heat enough to get perfect dissociation, you will not have that sorting out which always seems to follow the same law.

So much then for the passage from star to planet. Does this then throw any light upon the question—what I acknowledge to be one of the great points it is my duty to discuss—of the origin of the chemical constitution of the Earth?

Twice I have insisted upon this—that the hypothesis is almost worthless unless we assume very high temperatures. Now then, let us consider the Earth, which we know to be one of the interior planets, at the moment the ring—in which form it once existed according to the hypothesis—had been broken. By the breaking of this ring we have the future Earth, a mass of vapour in a state of incandescence.

I have already told you enough about the near similarity of the chemical constitution of the earth and sun to justify me in again asking you to let me see in the existing sun just such a mass of matter as our Earth then was. Now then, we simply go over the same line of facts again. This list of metals, with the exterior metalloids, must now do duty, not as it did before, for a nebula before it threw off its rings, but for our own Earth, after the time when a ring had formed to become the Moon ultimately. What would happen?

We know for certain that the Earth is now a cool body; but I do not think we know that with any greater certainty than we know that the Earth was once a very hot body; therefore there has been a process of cooling going on. Now I want you to answer for yourselves this question, What would be the stages of the cooling? We have, by hypothesis, metalloids outside—metalloids not in combination with metals, in consequence of the high temperature. Such as the solar condition is now, such doubtless was the terrestrial condition then. What is the first process then that takes place on

cooling?—combination. What then will be the process of combination? The metals and the metalloids will combine, according to their position in the present atmosphere of the sun, in the then atmosphere of the Earth. If, let us say, oxygen and chlorine cannot combine with hydrogen at a particular stage of temperature, they may go lower down, and attempt to combine with calcium and magnesium. But it is certain that if at any time they could have combined with magnesium and calcium, they would have had no chance of combining with iron, because iron was shielded by this enormous buffer of the upper metals. So that we ought to find that the crust of the Earth in the main consists of combinations of metalloids with those metals which exist highest in the atmosphere of the sun. Now it is not necessary that I should state any detailed facts on this point, because Professor Roscoe has already done that for me. I am sure you will all at once grasp that the composition required by the state of things I have pictured is exactly such a composition as Dr. Roscoe has brought before you; and if that is not sufficient I will read this extract from a work by an eminent geologist, Professor Prestwich. This is what he says about the composition of the Earth's crust:—

"The whole number of known elements composing the crust and atmosphere of the Earth amount only to sixty-four, and their relative distribution is vastly disproportionate. It has been estimated that oxygen in combination forms by weight one-half of the Earth's crust; silicon enters for a quarter; then follow aluminium, calcium, magnesium, potassium, sodium, iron, carbon. These nine together have been estimated to constitute $\frac{977}{1000}$ of the Earth's crust. The other $\frac{23}{1000}$ consist of the remaining fifty-five non-metallic and metallic elements."[1]

Now I think that I shall carry you with me when I say that an hypothesis like the one which I have brought before you—an hypothesis due to Kant and Laplace—which leads to mental results so very near the truth of nature, if it cannot be accepted as actual truth, is so near the truth that it deserves that any amount of trouble shall be brought to bear upon it to test it more and more carefully, to find out its weak points and to promulgate its strong ones, in order to beget thorough work.

You see then that if the metalloids combine with this

[1] Prestwich, *The Past and Future of Geology.* Macmillan, 1875.

upper group of metals, two things happen—two points relative to the chemistry of the Earth, which are well worth further inquiry. It follows that a large mass of the interior of the Earth consists of pure metal - and as Dr. Roscoe has referred to that point I need not touch upon it further—and if the Earth is anything like the sun—and we have no reason to doubt their almost perfect similarity – we may be perfectly certain that a large portion of that metal will be iron. It is quite possible that the magnetic state of the Earth—for the Earth is a great magnet—may be connected with the existence of this enormous mass of perfectly pure iron low down in the Earth. I am not recalling your attention to the existence of this pure iron with any commercial view, but it is important that we should learn all we can in regard to the Earth's magnetism, upon which our commerce so largely depends.

Another point is this, if the history of the Earth and the history of the other planets, so far as the chemical nature of the crusts goes, is a history of the descent of the metalloids upon the metals, *we must regard the atmosphere of any planet at any time as the mere residuum which has been left after all possible combination has taken place.* Our own atmosphere consists of oxygen and nitrogen—still uncombined, fortunately—and of aqueous vapour, a combination of oxygen with the highest known metal which we see on the list.

This consideration at once explains how it is that in the moon—which at one time doubtless was the scene of activities of a geological character probably far greater than anything which took place here; that in the moon—of which I bring before you a very beautiful portrait by Mr. Rutherfurd, of New York—so far as we know, there is now no atmosphere at all; or, at all events, if any atmosphere exist there, it is one so slight that scarcely a remnant of the pure gases has been left, and no aqueous vapour.

This brings us to several very interesting questions regarding the Earth's future; but I feel that I shall not be justified in entering upon them. I trust, however, with regard to the past, that you will be content to see, in the facts that I have ventured to bring before you, that chemists really would be justified in giving great attention to the study of the chemical nature of non-terrestrial matter, in order that the true chemistry of the Earth may be better understood.

LONDON:
R. CLAY, SONS, AND TAYLOR, PRINTERS,
BREAD STREET HILL,
QUEEN VICTORIA STREET.

WORKS BY J. NORMAN LOCKYER, F.R.S.

PRIMER OF ASTRONOMY. With numerous Illustrations. Third Edition. 18mo. 1*s.*

ELEMENTARY LESSONS IN ASTRONOMY. With numerous Illustrations and Coloured Diagram of the Spectra of the Sun, Stars, and Nebulæ. New Edition. 18mo. 5*s.* 6*d.*

QUESTIONS ON THE SAME, 1*s.* 6*d.*

THE SPECTROSCOPE AND ITS APPLICATIONS. With numerous Illustrations. Second Edition. Crown 8vo. 3*s.* 6*d.*

CONTRIBUTIONS TO SOLAR PHYSICS. With numerous Illustrations, Coloured Plates, etc. Royal 8vo. 31*s.* 6*d.*

STAR-GAZING: PAST AND PRESENT. Lectures delivered at the Royal Institution; with Notes and additions by G. M. Seabroke, F.R.G.S. With numerous Illustrations. Royal 8vo. [*Nearly ready.*

EDITED BY J. NORMAN LOCKYER, F.R.S.

THE APPLICATIONS OF PHYSICAL FORCES. By A. Guillemin. Translated by Mrs. J. N. Lockyer. With numerous Illustrations, Coloured Plates, etc. Royal 8vo. 36*s.*

MACMILLAN AND CO., LONDON.

In Eighteen Monthly Shilling Parts. Part I. on April 1st.

(*Also complete in One Vol. royal, 8vo., cloth elegant, 31s. 6d.*)

THE FORCES OF NATURE:

A POPULAR INTRODUCTION
TO THE STUDY OF PHYSICAL PHENOMENA.

By AMÉDÉE GUILLEMIN.

Translated from the French by Mrs. Lockyer, and Edited, with Additions and Notes, by J. Norman Lockyer, F.R.S.

WITH FOUR HUNDRED AND FIFTY ILLUSTRATIONS.

"The method of pictorial illustration, accompanied as it is by descriptions of singular clearness, makes the experiments as easy to understand as though they were actually performed before the reader. There are 450 of these illustrations, all well executed, and so admirably fitted to the text as to make the book interesting to young people, while it is at the same time worthy of the notice of the student."—*Daily News.*

"Altogether the work may be said to have no parallel, either in point of fulness, or attraction as a popular manual of physical science."—*Saturday Review.*

"It would be difficult to speak in tones of exaggerated praise in favour of this work. It is just what a popular instructor should be. We can commend it cordially to all those who wish, without going deeply into science, to investigate and understand the general laws by which Nature acts."—*Standard.*

MACMILLAN AND CO., LONDON.

MACMILLAN & CO.'S SCIENCE CLASS BOOKS.

ANATOMY.—ELEMENTARY LESSONS IN ANATOMY. By St. George Mivart, F.R.S. With numerous illustrations. 18mo. 6*s* 6*d*.

ASTRONOMY.—POPULAR ASTRONOMY. By Sir G. B. Airy, Astronomer-Royal. New Edition. With Illustrations. 18mo. 4*s*. 6*d*.

ASTRONOMY.—ELEMENTARY LESSONS IN ASTRONOMY. By J. Norman Lockyer, F.R.S. New Edition. With Illustrations and Coloured Diagram of the Spectra of the Sun, Stars, and Nebulæ. 18mo. 5*s*. 6*d*.—QUESTIONS ON THE SAME, 1*s*. 6*d*.

BOTANY.—LESSONS IN ELEMENTARY BOTANY. By Professor Oliver, F.R.S., F.L.S. New Edition. With Illustrations. 18mo. 4*s*. 6*d*.

CHEMISTRY.—LESSONS IN ELEMENTARY CHEMISTRY. By Professor Roscoe, F.R.S. New Edition. With numerous Illustrations and Chromolithographs of the Solar Spectra. 18mo. 4*s* 6*d*.

CHEMICAL PROBLEMS, adapted to the Same. By Professor T. E. Thorpe. With KEY, 18mo. 2*s*.

CHEMISTRY.—OWENS COLLEGE JUNIOR COURSE OF PRACTICAL CHEMISTRY. By F. Jones. Preface by Professor Roscoe. New Edition. 18mo. 2*s*. 6*d*.

LOGIC.—ELEMENTARY LESSONS IN LOGIC, Deductive and Inductive. By Professor Jevons, F.R.S. With copious Questions and Examples and a Vocabulary of Logical Terms. New Edition. 18mo. 3*s*. 6*d*.

PHYSIOLOGY.—LESSONS IN ELEMENTARY PHYSIOLOGY. By Professor Huxley, F.R.S. New Edition. With numerous Illustrations. 18mo. 4*s*. 6*d*.—QUESTIONS on the Same, 1*s*. 6*d*.

POLITICAL ECONOMY FOR BEGINNERS. By Millicent Garrett Fawcett. With Questions. New Edition. 18mo. 2*s*. 6*d*.

PHYSICS.—LESSONS IN ELEMENTARY PHYSICS. By Professor Balfour Stewart, F.R.S. New Edition. With Coloured Diagram and numerous Illustrations. 18mo. 4*s*. 6*d*.

STEAM. — AN ELEMENTARY TREATISE ON STEAM. By J. E. Perry, B.E., Whitworth Scholar, late Lecturer in Physics at Clifton College. With Illustrations, Numerical Examples, and Exercises. 18mo. 4*s*. 6*d*.

NATURAL PHILOSOPHY FOR BEGINNERS. With numerous Examples. By I. Todhunter, M.A., F.R.S. Part I. The Properties of Solid and Fluid Bodies. 18mo. 3*s*. 6*d*. [*Part II. in the Press.*

PHYSICAL GEOGRAPHY.—ELEMENTARY LESSONS IN. By Archibald Geikie, F.R.S., Murchison Professor of Geology, etc., at Edinburgh. With numerous Illustrations. 18mo. [*Nearly Ready.*

*** *OTHERS TO FOLLOW.*

MACMILLAN AND CO., LONDON.

3 0112 061408032

SCIENTIFIC WORKS.

THE SPECTRUM ANALYSIS. By Professor Roscoe, F.R.S. With Engravings, Maps, and Chromolithographs of the Spectra of the Chemical Elements and the Heavenly Bodies. Third Edition. Royal 8vo. 21*s.*

ASTRONOMICAL MYTHS. Based on Flammarion's "The Heavens." By J. F. Blake. With numerous Illustrations. Crown 8vo. 9*s.*

THE KINEMATICS OF MACHINERY. A Theory of Machines. By F. Reuleaux. Translated and Edited by A. B. W. Kennedy, C.E., Professor of Civil Engineering in University College, London. With 450 Illustrations. Royal 8vo. 21*s.*

EXPERIMENTAL MECHANICS. Lectures delivered at the Royal College of Science for Ireland. By R. S. Ball, M.A., Professor of Applied Mathematics and Mechanics. With numerous Illustrations. Royal 8vo. 16*s.*

THE CHEMISTRY OF THE CARBON COMPOUNDS; or Organic Chemistry. By C. Schorlemmer, F.R.S. With numerous Illustrations. Royal 8vo. 14*s.*

CHEMISTRY.—A COMPLETE TREATISE ON CHEMISTRY. By Professors H. E. Roscoe and C. Schorlemmer. With numerous Illustrations. Royal 8vo. [*Nearly ready.*

CAVE HUNTING. Researches on the Evidence of Caves respecting the Early Inhabitants of Europe. By W. Boyd Dawkins, F.R.S. With numerous Illustrations. Royal 8vo. 21*s.*

MACMILLAN AND CO., LONDON